THE USE OF REPRESENTATIONS BY PHYSICS GRADUATE TEACHING ASSISTANTS

by

Stephen L. Pellathy

B.S., Ohio University, 1994

M.S., Cornell University, 1997

M.A., University of Pittsburgh, 2003

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This dissertation was presented

by

Stephen L. Pellathy

It was defended on

August 4, 2009

and approved by

Adam K. Leibovich, Associate Professor, Physics and Astronomy

Chandralekha Singh, Associate Professor, Physics and Astronomy

Eric S. Swanson, Associate Professor, Physics and Astronomy

Dissertation Co-Advisor: Jennifer L. Cartier, Assistant Professor,

Instruction and Learning, School of Education

Dissertation Co-Advisor: Peter F. M. Koehler, Professor, Physics and Astronomy

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Stephen L. Pellathy, PhD

University of Pittsburgh, 2009

As a result of the crucial role representations play in teaching physics, their use is an important aspect of teacher preparation. This study involved three training sessions for physics graduate teaching assistants (TAs) that presented different representational tools or strategies targeting important topics that are common in introductory physics courses. The content of the training sessions relied on physics education research findings while their design was informed by the framework of pedagogical content knowledge (Shulman, 1986a).

Fourteen participants from the Department of Physics and Astronomy attended the training sessions as part of a required *Teaching of Physics* course during the fall of 2007. Data on the TAs' use of representations included pre- and post-assessments, and observations of them while teaching recitations. Four expert physics teachers who did not participate in the training sessions served as a contrast group through the completion of the written measures.

The data show that the TAs recalled the content of the training sessions two to three weeks following the sessions. However, when teaching these topics in their recitations the TAs did not use the representations from the training sessions. They still relied primarily on a narrow selection of well-established representations such as mathematical representations and free body force diagrams. In addition, many did not follow established problem solving steps that were also a part of their training. This minimal impact of the training sessions on their teaching is

explained in part by the TAs' lack of specialized content knowledge, a type of subject matter knowledge needed for teaching (Ball et al., 2008).

Based on the findings of this study, future TA training sessions should be designed to explicitly focus on both representational strategies and the specialized content knowledge required to successfully implement the strategies.

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CHAPTER 1: INTRODUCTION

Beginning graduate students in physics departments at research universities face a host of new challenges. Their first year typically includes required core courses, preliminary and/or comprehensive examinations, and for many of them duties, required by a funding source. Whether graduate students are funded as teaching assistants (TAs), research assistants, or by fellowships, their ultimate objective is to complete a PhD dissertation research project.

Considering those who teach, few have any prior teaching experience. Though many departments and universities offer TA training courses, most are very short (a day or two) and focus mainly on the mechanics of teaching such as talking loudly and writing legibly. Several years ago I participated in the Chemistry Department's new TA training at the University of Pittsburgh which consisted of two days devoted exclusively to safety. In contrast to such minimal training, TAs' potential impact on undergraduate students is enormous: In U.S. physics departments alone, teaching assistants teach over 250,000 students annually (AIP, 2006). In addition to the large number of students they impact while in graduate school, many TAs continue to teach as faculty members at colleges and universities after graduation.

The driving purpose behind this study was to better understand how to improve TAs' knowledge of the skills, strategies, and content necessary for teaching. To that end, the TA population selected for this study participated in three training sessions aimed at improving their teaching knowledge and skills. Such research requires both knowledge of physics and knowledge of educational theories and is not the typical research done in most physics departments, although physics education research (PER) is now a growing field. To the extent that universities are about education as well as research, it is in the interest of our profession and those it serves to engage the next generation in the "scholarship of teaching" (Boyer, 1990, p. 16).

1.1 BACKGROUND

A search for information about improving undergraduate science education yields an extensive literature printed in newspapers, news magazines, and academic journals. A similar search for information about improving the teaching abilities of graduate teaching assistants, however, yields almost nothing. Locally, within the Department of Physics and Astronomy at the University of Pittsburgh, three important elements have brought more attention to the improvement of teaching in recitations, providing a context within which such improvements are both desirable and possible.

1.1.1 Growth of PER in Department

One factor that led to more attention being paid to recitations and TA training was the growing visibility of PER in the Department. Professor Singh has been pursuing PER in the Department for almost two decades, and her efforts have led to an increased acceptance of PER as a crucial resource for fulfilling the Department's teaching mission more effectively. Among her many contributions to the Department, Professor Singh created a resource room (2000; 2002) and, jointly with Professor Koehler, won a grant to install clicker (or student response) systems in all three introductory physics lecture halls. Both enhancements are now widely used by the faculty. She conducted numerous research studies, most notably on student difficulties with quantum mechanics (2001; 2006), which were at the forefront of extending PER to upper level physics classes. In addition she has collaborated with many researchers outside the Department. The growing interest among graduate students to pursue PER for their dissertations is buoyed by external funding obtained by Professor Singh. Also, thanks to her leadership, several nationally important researchers have visited the campus; all have been received with interest and enthusiasm, underscoring the importance of PER to the Department's future.

1.1.2 Internal study regarding recitations

In 2004 the Department Chair formed a committee comprised of Professors Swanson (chair), Johnsen, Koehler, Singh, and Turnshek to review the effectiveness of recitations. The committee's findings were presented in a report called *Recitation Reform in the Department of Physics and Astronomy* (2005) that contained recommendations aimed at revamping the Department's "'traditional' recitation structure" (p. 3). A specific recommendation regarding the *Teaching of Physics* course called for teaching effective pedagogy to TAs by drawing on PER findings on how students learn physics and what common misconceptions they hold.

1.1.3 Changes to *Teaching of Physics* course

To the credit of the Department, a one-semester *Teaching of Physics* course has been required for all graduate students for approximately three decades, although its teaching was often neglected in light of teaching the core requirements. Under the leadership of Professor Koehler, with assistance from Professor Singh, it has undergone significant changes during the past few years along the lines outlined in the *Recitation Reform* report. Discussions on technical aspects of teaching have been enhanced by videotaped mock recitations and the graduate students are being introduced to many of the key findings of PER.

1.1.4 Summary

Within this context, I developed a research plan centered on supporting TAs in becoming more effective recitation teachers through the insertion of specially designed training sessions into *Teaching of Physics*. The sessions draw on findings of PER relevant to teaching introductory physics. They are accompanied by an assessment of which aspects of the training sessions had an impact and an analysis of why some aspects did and others did not resonate. The assessments directly measured the impact of the trainings, and also provided insight into the knowledge required for implementing the strategies found in the PER literature. The next section presents my research questions which target these two aspects (impact and knowledge).

1.2 RESEARCH QUESTIONS

I investigated the training sessions by way of two sets of research questions. The first set asked about the impact of the training sessions, and the second asked about the underlying knowledge of the TAs that enabled their implementation of the tools and strategies.

Impact Research Questions:

1. *Was TAs' use of representations changed by training sessions on multiple representations?*
2. *Did TAs rely on the problem solving steps explicitly outlined in the training sessions to support the use of representations?*

Knowledge Research Questions:

1. *What knowledge for teaching do physics graduate TAs possess or lack?*
2. *Can this knowledge for teaching be classified consistently into empirically generated categories in harmony with the typology of Ball et al. (2008)?*

The representations and problem solving steps on which the training sessions focus constitute pedagogical tools. As such they are classified in the literature as *pedagogical content knowledge*. The impact research questions ask if these pedagogical tools have been implemented with fidelity. The knowledge research questions, however, ask about the underlying knowledge needed to implement the strategies, knowledge which, though needed for teaching, is considered *subject matter knowledge*. This distinction is symbolically represented in Figure 1. Both sets of questions, and both types of knowledge, are revisited in depth in later chapters.

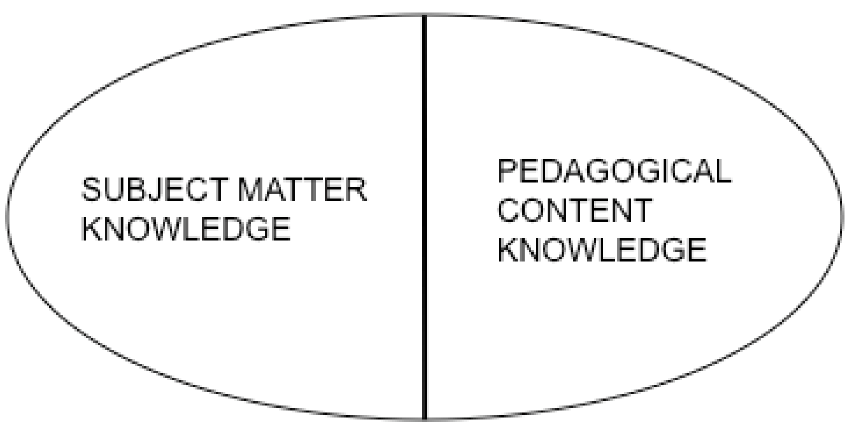


Figure 1: Two complementary aspects of knowledge for teaching (adapted from Ball et al., 2008).

Representations are central in this study. I define representations in accord with Larkin & Simon (1987, p. 66): non-sentential, non-verbal, static diagrams, pictures, or mathematical expressions that explicitly preserve information about the relationships between the components of a problem. It is important to note that diagrams include those labeled as such, for example free body force diagrams, as well as those that are commonly called graphs, charts, or sketches. This is discussed further in 2.1.4.

1.3 OVERVIEW OF DISSERTATION

After establishing the need for studies on teaching assistants, the second chapter discusses the relevant PER findings that the TA training sessions drew on. The topics of the training sessions are: 1) forces in equilibrium, 2) work-energy, and 3) torques. I assert that the *pedagogical content knowledge* framework is an appropriate choice for designing the sessions. The chapter concludes with a restatement of the impact research questions. In the next two chapters I justify my methodological approach and provide the details of my data collection and analysis. Concisely stated, in recitations TAs tend *to solve* problems instead of *to teach* students how to solve problems. This means that they follow a narrow, procedural approach to problem solving instead of a broader approach focused on conceptual learning. The fifth chapter offers explanations of the patterns emerging from the data, specifically calling attention to the knowledge required for teaching which, if lacking, hampers attempts at more effective instructional practices. Understanding the findings relies on connecting pedagogical content knowledge to subject matter (physics) knowledge under the umbrella of *knowledge for teaching*.

I conclude by discussing implications and certain shortcomings of this study and directions that future studies might take.

CHAPTER 2: CONCEPTUAL FRAMEWORK

With the growth of PER has come a large increase in our knowledge of the difficulties undergraduate students have in understanding physics. As shown on its physics education group's website (http://www.phys.washington.edu/groups/peg/Gradprogram.html), since 1979 the University of Washington's PhD program alone has produced seventeen (17) dissertations and many more articles on understanding students' difficulties with a variety of topics within physics. McDermott and Redish's (1999) *Resource Letter* cites 135 such studies (though even more might be classified as such) out of a total of 224 citations. The *Letter* references only eight (8) articles on instructional strategies to teach problem solving, and cites an additional eight (8) articles under a section called "Guidance for instructors." A quintessential instructional strategy that developed from studies on student understanding is *Peer Instruction* (Crouch & Mazur, 2001). One important feature of this strategy is to drive home to students the contrast between their knowledge and scientifically accepted theories. However, the strategy does not change the instructor's knowledge or skills. There is no systemic focus on TA or instructor training to leverage this ever-growing knowledge base. Clearly PER has not taken the next step of disseminating researched findings to the next generation of educational leaders.

The limited attention that teaching receives in the PER community likewise does not provide a model for designing and delivering training sessions. The approach of Jossem's *Resource Letter* on the education of physics graduate assistants (Jossem, 2000) is to compile a list of resources. Items on the list provide tips on teaching, resources for physics classroom demonstrations, and books on the history of physics to broaden the perspective of TAs and students alike. The *Letter* does not, however, deliver a framework for understanding teaching practice or the education of TAs. It fails to cite any sources that discuss one of the most important concepts for teacher training of the last two decades: pedagogical content knowledge. Shulman's articles (1986a; 1986b; 1987), some of the most cited publications in the education literature, are not referenced. This is not a direct omission by Jossem, but rather a reflection of 1) the continued focus of PER on understanding student thinking instead of other potential areas such as TA training, 2) departmental TA training efforts that focus on the mechanics of teaching or very specific recitation strategies, and 3) the divide between PER and educational research.

In a similar vein, in a recent guest editorial in the *American Journal of Physics*, two leading physics education researchers consider the future of PER (Heron & Meltzer, 2005). They begin by focusing on "research directions that have potential for deepening our understanding of how students learn physics" (p. 390.) Although in the next sentence they suggest that increased understanding of students' thinking should lead to more effective instruction, they do not devote any more discussion to developing a framework for how results from PER might find their way into the classroom in a systematic way.

A recent article by Dancy and Henderson (2007) entitled *Framework for articulating instructional practices and conceptions* characterizes traditional and reform instruction, extending the characterization to curricular materials. For example, they state that traditional classrooms involve one-sided (teacher) discourse whereas reform classrooms involve active student contributions. Pursuing the same theme, they later contrast the teacher as teaching versus guiding. But by what means can a TA achieve a reform style of instruction? The article does not explicitly discuss or organize the knowledge and skills that TAs need to become more effective teachers. Thus a gap exists between the wealth of knowledge developed by PER and its dissemination to teachers and instructors of undergraduate physics. There are many good results for instructors to draw on but no focus on the instructor, or if there is a focus it is on instructors being more engaging but not on expanding their knowledge base.

The rest of this chapter details specific PER findings on which the training sessions are based. Importantly, it embeds the training sessions in the framework provided by pedagogical content knowledge, an important part of knowledge for teaching. Placing PER results in this framework enables the systematic design and delivery of training sessions. The chapter concludes with a statement of my research questions.

2.1 PER FINDINGS USED IN THE TRAINING SESSIONS

As mentioned, PER has produced many studies that probe students' understanding of a variety of topics. As part of the probes, or in response to student difficulties revealed by them, a large literature on multiple representations for different physical scenarios has emerged (see citations within Meltzer, 2005; Rosengrant, Etkina, & Van Heuvelen, 2007; Kohl & Finkelstein, 2006; Dufresne, Gerac, & Leonard, 1997). The use of representations in teaching and learning has also received a great deal of attention in the education and cognitive science literature. Additionally representations are crucial in physics since they play heavily into the day-to-day research efforts of physicists, making them an aspect of teaching and learning that is authentically connected to the practice of doing physics.

The majority of PER studies directly involving representations focus on students' performance and the use of the representations. Rosengrant et al. (2007) divide such studies into three methodology-based categories: 1) conceptual learning, 2) problem solving, and 3) problem format. Conceptual learning studies typically focus on the impact on student learning when traditional word problems are accompanied by a variety of representations. Problem solving studies typically compare test results of students using one of several representations. Problem format studies typically test student performance on isomorphic problems posed in different representations. In general these studies have shown that students' ability to understand and use multiple representations is positively correlated with their learning. Students who grasp multiple representations possess a powerful advantage in problem solving (Dufresne et al., 1997). This correlation provides a justification for the training sessions to incorporate multiple representations.

Problem solving itself, with or without representations, is a crucial skill in physics. Therefore, after discussing multiple representations, I transition to describing recommended problem solving steps for force and energy problems. Drawing on all three of PER research areas on representations mentioned above, I organized the findings around the three topics of the trainings: 1) forces in equilibrium, 2) work-energy, and 3) torques.

2.1.1 Forces in equilibrium – first TA training session

The first training session was based on the results discussed in Minstrell's (1982) article, which provides a quintessential PER example of research on representations. Based on transcriptions of student/teacher conversations and examples of student pictures and diagrams, Minstrell found two dominant views among the student of the forces acting on a book at rest on a level table: a physicist's view that the table and gravity exert equal and opposite forces on the book and an alternate view that the only vertical force is gravity. In order to address the alternate student view, a strategy involving multiple representations was employed.

One part of Minstrell's strategy relied on a demonstration using a book as a prop. Students were asked to hold the book in their outstretched hands allowing them to feel the weight of the book. Another part of his strategy relied on the notion (Clement, 1993) of bridging analogies (available to Minstrell through correspondence with Clement and through Clement (1981)). In the bridging analogy, a spring is the anchor concept (diSessa, 1993), which connects through 'bridging' cases of foam and a flexible surface, to a rigid tabletop, as shown in Figure 2.

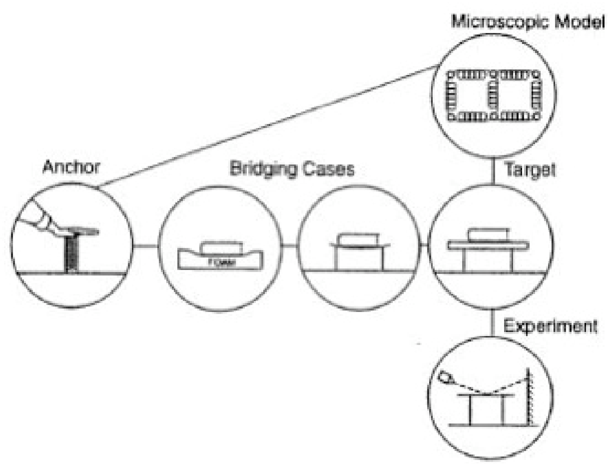


Figure 2: Bridging analogy.

As a final demonstration in Minstrell's (1982) study, the teacher showed that the table is in fact not completely rigid by use of an optical interferometer. By use of these different representations the teacher shifted students' views predominantly towards the physicists' view.

Clement's body of work on the aforementioned bridging analogies (detailed in Clement (1993)) warrants additional attention. Clement showed large pre-posttest gains in favor of those experimental groups in which bridging analogies played a central role in instruction. The strategy relies on students' prior knowledge being a mix of misconceptions and accurate anchoring ideas. Preconceptions, alternately called misconceptions, are deep-seated and well-formulated but inaccurate concepts that students hold prior to instruction. Anchoring ideas are similar in their robustness to preconceptions, but narrower in scope and accurate in capturing some aspect of a physical phenomenon. For example most students intuitively (and correctly) hold that a springy object compresses when a force is applied (the spring in Figure 2). This forms the basis for transforming the misconception that a table does not exert a force into the scientific view that the table does exert a force (target concept) by way of the bridging analogies. This strategy has been adapted for explaining friction and Newton's third law, among other concepts (Clement, 1993). Analogies are a powerful representational tool for teaching and learning physics.

Complementing the representations used in solving force problems are a series of components that are critical to effectively teaching force problems. These components make features in the problem and assumptions about the problem explicit, thereby aiding in the coordination of different representations. Table 1 lists these components and their definitions. The problem solving steps correspond to those recommended in most textbooks, though in many cases the steps are not explicitly delineated.

Component	Definition	Explanation or Example
Principle	Articulates force principle(s) that frame the problem	States Newton's second law, $\sum F = 0$, $\sum F = ma$, or similar
System	Chooses/defines a system	Articulates which objects are part of the system.
Motion	Characterizes the motion as stationary, constant velocity, or accelerating	States the type of motion and the physical (and/or mathematical) consequences of such motion.
Forces	Identifies forces	States types of forces featured in the problem.
Origin	Identifies the origin of forces (or the interaction which accounts for them)	Unambiguously specifies the cause of the forces on the object.
Axes	Defines coordinate axes	Draws or otherwise indicates coordinate axes.

Table 1: Components of solving force problems.

2.1.2 Work-energy – second TA training session

The second training focused on a representational tool called the energy bar chart (Van Heuvelen & Zou, 2001), which was developed to improve students' conceptual understanding of work-energy and conservation of energy problems. For energy problems the charts serve the same role that free body force diagrams play for force problems. Figure 3 illustrates the use of energy bar charts in three solutions to the same problem. A picture of a physical scenario is shown on top, with the dotted line delineating the designated system. The corresponding energy bar charts are shown below the pictures. Note that although the overall structure of the problem remains the same (initial energy + work = final energy), each of the scenarios results in different types and amounts of energy and work as reflected in the bar charts. The mathematical statements below the bar charts capture algebraically equivalent but physically distinct situations, which are fundamentally distinguished by the choice of what is included in the system and what belongs to the surroundings. In the cases on the left and in the middle, the initial compression of the spring is categorized as spring potential energy because the spring it part of the system. In the case on the right the spring, which is external to the system, does work on the system. Regarding the gravitational force, in the case on the left the car moving up the hill is categorized as a change in gravitational potential energy since the Earth is part of the system. In the middle and right cases, Earth is external to the system, and hence the gravitational force does work on the system.

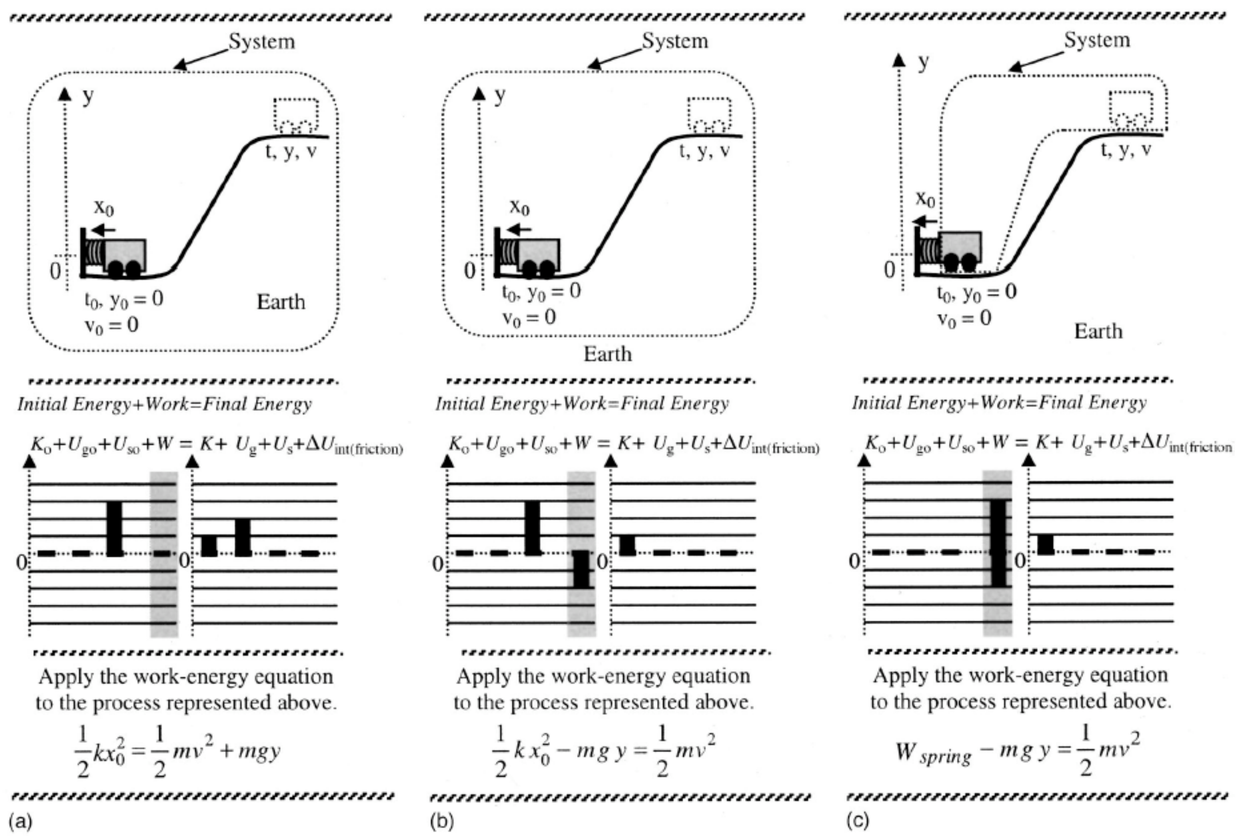


Figure 3: Energy bar charts

Table 2 shows a sequence of problem solving steps that were developed by Van Heuvelen and Zou (2001) for students to follow in order to enable their use of energy bar charts.

Energy bar charts are not found in many textbooks although *The Physics Active Learning Guide* (2006) incorporates them into student problems. Likewise although the problem solving steps shown in Table 2 correspond to the approach found in most textbooks, these steps are often not explicitly recognized or delineated.

1. Choosing a system - the object or objects of interest for the process being considered.
2. Characterizing the initial state and the final state of the process.
3. Identifying the types of energy that change as the system moves from its initial state to its final state and the signs of the initial and final energies of each type.
4. Deciding if work is done on the system by one or more objects outside the system as the system changes states.
5. Developing the idea that the initial energy of the system plus the work done on the system leads to the final energy of the system - the energy of the universe remains constant.
6. Constructing an energy bar chart - a qualitative representation of the work-energy process.
7. Convert the bar chart to a mathematical representation that leads to a problem solution.

Table 2: Sequence of problem solving steps for using an energy bar chart.

The steps in Table 2 form the basis of the components of energy problems summarized in Table 3. These mirror the components for solving force problems.

Component	Definition	Explanation or Example
Principle	Articulates energy principle(s) that frame the problem	Writes or says $E_{initial} + W = E_{final}$; $\Delta E = 0$; or similar.
System	Chooses/defines a system	Articulates which objects are part of the system.
States	Characterizes initial state and final state	Divides solution into initial/final parts or otherwise delineates initial/final states.
Types	Identifies types of energy (or how they transform)	States types of energy involved in the problem.
Work	Decides if work is done on/by the system	Unambiguously defines work done on/by the system.
External Forces	Identifies external forces	Unambiguously identifies which forces contribute to external work.
Axes	Defines coordinate axes	Draws or otherwise indicates coordinate axes.

Table 3: Components of solving work-energy problems.

2.1.3 Torque – third TA training session

The third training session addressed the concept of torque without adding a novel representational tool. In this case the approach was to highlight the equivalence of two methods of finding the torque by using an extended free body force diagram. In one case the lever arm is taken along the extended object and is multiplied by the perpendicular component of the force to find the torque. In the other case the lever arm is taken as the perpendicular distance between the "line of action of a force" and a parallel line that passes through the axis of rotation. Based on my own experience, many students struggle with the equivalence of these two formulations. Regarding torque problems, there is no well-articulated set of problem solving components, though the components in Table 1 provide a guide for important elements.

2.1.4 Types of representations

Relying on the studies that informed my training sessions, I now discuss the various types of representations that were part of the study. As mentioned earlier, written words that form sentential representations are not considered in this study – the representations addressed are considered diagrammatic (Larkin & Simon, 1987). It is important to note that while the global category diagrammatic representations is used, the terms "diagram" and "diagrammatic" have specific meanings in the context of physics as described below. Also, due to a methodological limitation of the study, gestures also were not considered because only audio recordings were made of the observations. Table 4 lists the types of representations considered in this study with a brief description of TAs' use of them. The subsequent discussion provides more details about each type of representation.

Representation	Description
Math	Uses mathematical equations to represent aspects of the problem.
Graph	Draws a graph typically showing change of some variable versus time on the x-axis.
Picture	Draws a sketch with or without adding coordinates, direction of motion, force vectors, or similar.
Analogy	Describes or explains the given scenario in terms of another scenario, highlighting relevant features of overlap.
Demo	Demonstrates part or aspect of problem with physical props.
Free Body Diagram	Draws a point particle indicating force vectors.
Extended Free Body Diagram	Draws an extended object indicating force vectors and/or torques.
Energy Bar Chart	Draws a chart with different types of energy.

Table 4: The representational types featured in the study.

2.1.4.1 Mathematical representation

Mathematical representation is fundamental to physics. It consists of formulas and equations which concisely capture physical relationships and interactions. From previous experience the use of mathematical representations by TAs is taken as a baseline for recitations. Studies show that student understanding of the physics is enhanced by the use of other representations. Importantly, in a case study on students' use of multiple representations in problem solving, Rosengrant et al. (2007) found a significant positive difference in the problem solving performance of students whose instruction explicitly stressed the use of representations other than mathematics. The experimental group was specifically asked to convert pictorial representations to mathematical ones and vice versa, or diagrammatic representations to mathematical ones and vice versa.

2.1.4.2 Graphical representation

Graphical representations of physical scenarios, especially changes over time, can be very powerful. Physicists rely on graphs to convey information concisely and understandably. Students struggle with graphs but once they learn how to use them, their ability to understand the concepts underlying the graphs increases (McDermott, Rosenquist, & van Zee, 1987). Graphical representations are an important component of an effective TA's toolbox, but no specific training session focused on their use.

2.1.4.3 Pictorial representation

Pictorial representations often provide students an insight into the physical scenarios described in physics problems. As such they are an invaluable part of the problem-solving skill set of students and, accordingly, the teaching skill set of TAs.

2.1.4.4 Analogical representation

Analogies have been shown to effectively draw upon students' prior knowledge to illuminate a new situation. As such, TAs with ready analogies can have a large positive impact on their students as described above in Minstrell (1982). An example of the use of analogies by (Podolefsky & Finkelstein, 2006) addresses the topic of electromagnetic waves. They concluded that students mapped aspects of electromagnetic waves to waves on a string or sound waves depending on which analogy instruction explicitly developed. In this case the connection is between new material and previously studied material.

2.1.4.5 Physical demonstration

Physical demonstrations have a long history in teaching physics, with modern demonstrations including A/V equipment and simulations (see simulations in 2.1.4.9). TAs in the Department have access to a large number of demonstrations, supported by a very capable staff. Many TAs, however, are unaware of this resource or avoid using it because of the preparation time required.

2.1.4.6 Free body force diagram

Free body force diagrams warrant their own category for two reasons: 1) they are critically important to teaching Newtonian mechanics, and 2) they are the most researched representational tool in physics (see Rosengrant, Van Heuvelen, & Etkina (2005) and references therein).

2.1.4.7 Extended free body diagram

Extended free body diagrams, like free body force diagrams, are important enough in physics to warrant special attention. Used primarily in rotational problems when the extension of the physical body cannot be abstracted to a point, these diagrams also show up in non-rotational problems as a mix between a sketch (pictorial representation) and a free body force diagram.

2.1.4.8 Energy bar chart

See discussion in 2.1.2.

2.1.4.9 Simulations

At the University of Pittsburgh physics TAs do not rely on technology as they teach recitation, so this representation does not show up in Table 4. Nevertheless, much work has been done recently on the use of computer simulations. Researchers at Colorado in particular have developed a host of applets (http://phet.colorado.edu/index.php) that illustrate many areas of physics. For example, Finkelstein et al. (2005) demonstrated that on exam questions students who used computer simulations to learn about DC circuits outperformed students who experimented with real circuits.

2.1.5 Summary

The representational types and problem solving steps discussed in this subsection formed the basis of the TA training sessions. They are the subject of the research questions, and understanding their use constitutes the central aim of this dissertation.

2.2 AN ANALYTICAL FRAMEWORK FOR THE TRAINING SESSIONS

The concept of pedagogical content knowledge (PCK) first appeared in Shulman's (1986a) address to the American Educational Research Association. Shulman (1987) describes PCK as that which distinguishes teachers of content from content specialists. PCK refers in part to domain-specific knowledge of students’ preconceptions and a variety of representations of concepts (for instance analogical or diagrammatic) geared towards overcoming students’ preconceptions. In its original conception, pedagogical content knowledge was articulated as one of three types of knowledge needed for teaching, the other two being domain or subject matter content knowledge and curricular knowledge. Curricular knowledge has since been classified as pedagogical content knowledge (Ball, Thames, & Phelps, 2008); it does not enter into this dissertation. That leaves two types of knowledge under consideration: subject matter knowledge and pedagogical content knowledge.

Subsequent elaborations of Shulman's early articles – they have been cited many thousands of times – occur in so many articles that it is impossible to name them in any meaningful way. However, the following were key references for this dissertation: Shulman (1986b), Shulman, (1987), Wilson, Shulman, and Richert (1987), Shulman & Grossman (1988), Grossman (1988), Ball (1990), Ball (2000), Magnusson, Krajcik, and Borko (2002), and Ball et al. (2008). The vast number of articles from all content areas which rely on the framework of PCK attest to the usefulness of this concept.

Developing teacher training programs based on the notion of PCK has become an accepted model of professional development at the K-12 level (van Driel, Verloop, & de Vos, 1998). Although the framework of PCK was developed with K-12 teachers in mind it, readily applies also to the knowledge needed by TAs to teach undergraduate courses. After describing PCK as a way to conceptualize teachers' requisite knowledge, I highlight several studies within physics education research that focus on student understanding and learning. Concrete examples from PER with proven results in terms of student outcomes can be systematically expressed in the framework of pedagogical content knowledge for use in TA training sessions.

While being leveraged to design teacher training programs, PCK, like other powerful theoretical frameworks, also suggests aspects of its own further development and refinement. For my research I relied on certain aspects of PCK, namely those that aligned with areas of active research in physics education as detailed in this chapter. Within physics these aspects are unique, and would not, for instance, be the same within a study on mathematics or chemistry. Using a custom-designed approach accords well with current thinking that PCK is content dependent or even topic specific (Magnusson et al., 2002). In Kuhnian terms, PCK is the guiding paradigm of a growing part of educational research; the shift began over two or three decades ago, but the details of its use and applicability are still being developed.

Grossman (1988) divided PCK into four aspects: 1) a high level conception about the purposes and goals of teaching certain subject matter; 2) an understanding of students' prior subject matter knowledge, including their preconceptions of that knowledge; 3) a familiarity with multiple organizational structures of the curriculum and curricular materials; and 4) a variety of representations and instructional strategies for the topics covered. My study brings awareness to aspects 2) and 4) in the context of introductory physics. These issues are linked to the research questions investigating the impact of the training sessions on TAs' practice.

As an example of the difference between domain content knowledge and PCK, consider the "at rest" condition of a book on a table. Physicists know that a book on a table has an upward normal force exerted on it by the table that balances the downward gravitational force exerted on it by the Earth. This knowledge is subject matter knowledge. What physicists may not realize is that many introductory students have a preconception that inanimate objects, like a table, cannot exert a force (Minstrell, 1982). Students often incorrectly identify only the gravitational force when the book is "at rest" on the table, claiming that the table just blocks the fall of the book without exerting a force. They subsequently incorrectly draw the free body force diagrams that are required in many such problems. In this case, having pedagogical content knowledge means understanding that students struggle with the idea of a table exerting a force. PCK opens the door to interpreting a mistaken free body force diagram as possibly resulting from a deep-seated underlying misconception instead of a clerical error. Differentiating between misconceptions and minor errors can lead to vastly different instruction. Furthermore, PCK entails applying teaching strategies targeted at overcoming such misconceptions.

Each TA training session focused on a goal for student understanding, which was unpacked through the lens of the knowledge and skills TAs needed in order to implement strategies to more effectively teach the goal. The use of multiple representations was chosen as the TA skill bridging the gap between students' prior knowledge and students' learning goals.

While PCK as an abstract idea adds theoretical unity to the findings of physics education research, its value would be greatly reduced unless it also provided new approaches to improve teaching and ultimately student learning. Most studies involving the PCK have focused on:

- Defining such knowledge in a given domain (Ball, 1988; Ball, 1990; Ball et al., 2008; Borko et al., 1992; Leinhardt & Smith, 1985),
- Understanding how such knowledge impacts teaching (Wilson & Wineburg, 1988; Grossman, 1988; Grossman, 1990), or
- Assessing teachers' ability to learn such knowledge (van Driel et al., 1998; Halim & Meerah, 2002; Dani, 2004).

In terms of impact, recent studies report a significant positive relationship between teachers' PCK and student achievement (Gess-Newsome & Lederman, 2001). The most comprehensive of these studies (Hill, Rowan, & Ball, 2005) looked at first and third grade teachers of mathematics. The researchers collected achievement data from both teachers and students in 115 elementary schools over four years. Teacher data came from logs and an annual survey while student achievement was measured by a nationally accepted exam. The results of the study show great promise in developing teachers' mathematical knowledge for teaching. A specific result of interest to my research found that teachers' mathematical knowledge for teaching correlated strongly with student gains. By dividing the teachers into cohorts of high knowledge and low knowledge the researchers demonstrated that students of high knowledge teachers had significantly higher gains on standardized tests. Interestingly, higher knowledge was correlated to higher gains even at the first grade level where it had been assumed that the elementary nature of the content would mitigate differences in teacher knowledge. By extension, though physics TAs may find the content of introductory physics to be simple, increasing the TAs' PCK may have a positive effect on student learning.

Interestingly, Hill, Ball, and their colleagues have clarified their classification of knowledge during the time period from 2005 to 2008. In 2005 they referred to *content knowledge for teaching* alternately as pedagogical content knowledge or *specialized knowledge that is not pedagogy*. In equating it to PCK they quote Shulman (1986a) who stated that subject matter knowledge for teaching defined PCK. In equating it with specialized knowledge they are not clear whether or not this is part of PCK, nor does their comment that it is not pedagogy does not enable us to infer that it is not PCK. By 2008, however, they referred to their 2005 study as being about subject matter knowledge that is distinct from PCK but required for teaching – in other words, "content knowledge for teaching" is specialized knowledge in the sense of Ball et al. (2008).

Several smaller studies have focused more attention on specific aspects of PCK and teachers' ability to learn these aspects. For example, van Driel and his colleagues (1998) found that those chemistry teachers who were able to discuss anomalous results with their students prompted conceptual change in them, as demonstrated in questionnaires and interviews. The chemistry teachers attended a PCK-centered workshop, as part of a professional development cycle, from which they applied their knowledge to their classrooms. This study's relevance to my research lies not only in the impact on the teachers' students, but the effectiveness of workshops on increasing their PCK. My research also focuses primarily on possible changes in teacher PCK resulting from workshops as contexts to engage in PCK-developing activities.

2.3 IMPACT RESEARCH QUESTIONS

The impact research questions that defined the problem space of my study are derived directly from the empirical and theoretical considerations of this chapter. The first pair of questions asked about the impact of the TA training sessions around the areas of focus of representations and problem solving steps. In other words, were the TAs able to do what was modeled in the training sessions? Were they using representations as part of their instruction?

Impact Research Questions
1. *Was TAs' use of representations changed by training sessions on multiple representations?* 2. *Did TAs rely on the problem solving steps explicitly outlined in the training sessions to support the use of representations?*

Table 5: Research questions investigating the impact of the training sessions.

A second pair of research questions emerged around the subject matter knowledge needed to implement the strategies of using multiple representations and problem solving steps offered in the trainings. The design of the training sessions focused on instructional strategies, assuming adequate subject matter knowledge to implement the strategies. In addition to the strategies themselves, *what else* did TAs *need* to know to implement the content of the training? This question is not about what TAs *should* know but rather what evidence emerged from the study of the training sessions and their impact on TAs' teaching. A theoretical complement asked about classifying such knowledge according to existing frameworks such as the one proposed by Ball et al. (2008). These questions are presented and addressed in Chapter 5.

2.4 SUMMARY

This chapter presented PCK as the organizing framework of the training sessions. I relied on specific aspects of PCK aligned to the specific resources within PER, namely focusing on the use of multiple representations and problem solving steps to achieve student learning goals. Since I worked with physics TAs I assumed a high level of subject matter knowledge. This allowed me to focus on representations that require physics content knowledge. Results from other studies find value in increasing teachers' PCK, thereby motivating my approach. The two research questions probe the impact of the training sessions on the TAs' teaching.

Before continuing, I wish to acknowledge that physics education research has long valued, and continues to value, many of the components of pedagogical content knowledge (though not named as such), in particular the focus on knowledge of student understanding. More than just adding a new term to the literature, however, Shulman (1986a) conceived of a new broad framework for understanding the type of content knowledge that teachers need specifically for teaching. PCK adds cohesion and structure to many existing studies, offering a systematic way for physics education researchers to make sense of and to disseminate their results.

CHAPTER 3: METHODOLOGY AND DATA ANALYSIS

This chapter discusses the data collection and analysis used to assess the training sessions. It details the combination of qualitative and quantitative measures used in this study. Specifically it describes the introductory courses in the study, the research design, the recruitment and selection of participants, the training sessions, the data sources, and the data analysis.

3.1 INTRODUCTORY PHYSICS COURSES

The three training sessions at the heart of this study involved three different topics central to introductory physics. The Department offers four types of introductory physics courses: the first type includes several quite general courses that are designed for non-science majors to fulfill the General Science requirement; the second type is the honors version of the two-semester introductory course, which is primarily taken by physics majors and the top engineering majors. These two types of courses were not part of the study. The remaining two types of courses are the algebra-based and the calculus-based introductory course sequences (two semesters each). They are offered multiple times each semester, including summer, and serve the largest number of undergraduates. Most students take them to fulfill a requirement for their major. Thus engineers and physical science majors primarily populate the calculus-based introductory courses while life science majors and other students preparing for health-related professions take the algebra-based introductory course. These courses were chosen for this study not only because of the large number of students and TAs involved with them, but also because most previous PER studies from which I am drawing material for my training sessions focus on such introductory physics courses (Arons, 1996).

3.2 RESEARCH DESIGN

This study was designed to access large amounts of detailed data on a few individual participants. There were not enough resources available to train and subsequently to observe and transcribe the observations of the recitations for a large number of TAs. This type of study is a "small N" study, where "N" refers to the number of participants. A small N, however, does not mean a small amount of data. To the contrary, looking at participants in detail generated complete transcripts (large amounts of data) on the specific recitations under investigation.

The methodology is mixed-method in that it used both quantitative and qualitative data and is of the concurrent triangulation type (Creswell, 2002, p. 224; Creswell, 2008). Such studies have increasingly become part of the PER landscape (Plano-Clark, 2005). The term "concurrent" means that the quantitative and qualitative nature of the data did not determine the sequencing of data collection. The term "triangulation," as its colloquial meaning suggests, refers to the use of multiple data sources to support a finding, as further explained in the following sub-section. *Concurrent triangulation* has four distinguishing features:

- Implementation – Data collection is concurrent throughout the research study.
- Priority – Data sources whether quantitative or qualitative are given equal weight.

- Stage of integration – Data sources are integrated (or synthesized) during the analysis phase which follows data collection.
- Theoretical perspective – A theoretical perspective is not required for concurrent triangulation, but it is allowed. In this case the perspective is constructivism, which concretely means that the participants were provided with opportunities to engage in PCK-developing experiences.

3.2.1 Triangulation

Mixed-method studies often rely on triangulation in order to improve the validity and reliability of results (Golafshani, 2003). Triangulation refers to multiple data sources providing information on clearly articulated aspects of a research study (Creswell & Plano Clark, 2007). Validity and reliability are complementary terms (Anderson & Arsenault, 1998). Validity means the "extent to which what we measure is what we expected to measure" (p. 13). *Internal* validity would be established in this study if there were consistency in the types of responses to the questions on the written measures among the TAs, the members of the class, and the experts. A measure of *external* validity would be provided if findings similar to mine were reported in other research studies in a variety of contexts. Reliability "refers to consistency in measurement" (p. 12). Reliability is measured by the parameter kappa (defined in 3.6.4), which compares the reliability coder's level of agreement with my coding of the written measures and the observations. Combining qualitative and quantitative approaches strengthens a study by controlling for bias in any one measure (Golafshani, 2003). Ultimately triangulation allows for generalizability of the results of a study.

3.2.2 Design-based research methodology

The research methodology is also design-based (Brown, 1992; Brown & Campione, 1996; DBRC, 2003), a favorable strategy since my research occurred in a natural classroom setting. According to Brown, design-based research is an "attempt to engineer innovative educational environments and simultaneously conduct experimental studies of those innovations" (1992, p. 141). In other words, design studies simultaneously contribute to both research and practice. Physics education research is successfully adopting this approach (Hake, 2004).

This methodology was crucial since I implemented my training sessions as part of a class taken by TAs, and then, in turn, the TAs were observed while they were teaching actual recitations. The power of a design-based methodology is illustrated by the following example: during the course of my study I noticed that when TAs were teaching their students about the conservation of energy problems, they did not clearly delineate between "the system" and "the surroundings." As a consequence of this observation I designed 'post post 2' assessment to probe the TAs' knowledge of defining the system. Thus the measures in the study were adjusted in real time.

3.3 RECRUITMENT AND SELECTION OF SUBJECTS

3.3.1 Recruitment and selection of participants

Study participants were divided into two levels, *TA* and *Class*. Participation at the *TA* level involved recitation observations while participation at the *Class* level did not. The recruitment of subjects began with those enrolled in Physics 2997 - *Teaching of Physics*, a required course for all first-year graduate students in the Department. All ten students enrolled in the class opted to join the study. Since the course was required, these participants were not compensated for their time during the three training sessions that were held during class time. Those who participated at the *TA* level were compensated for time spent in the study beyond the training sessions at the rate of $12 per hour.

In addition, I recruited four teaching assistants who were assigned to either the calculus-based or the algebra-based introductory physics courses but not concurrently enrolled in *Teaching of Physics*. Of these, two participated at the *TA* level and two at the *Class* level, although all four only came to the three training sessions. The two who participated at the *Class* level were undergraduate seniors who had been selected to be TAs as a result of their excellent academic performance as students in the introductory courses. These four participants were also compensated at $12 per hour for all of their time commitments, including their participation in the three training sessions.

Of the fourteen participants, the four at the *TA* level were arrived at through opportunity sampling. Eight of the fourteen were grading or teaching laboratory sections instead of recitations, and two were co-teaching, but their partner assistants opted not to participate in the study. Of the four, two were first-year graduate students and two were upper-class graduate students had taken an earlier version of this course (pre-Koehler) and had taught before. Table 6 summarizes the participants' status.

	TA	Class	PARTICIPANTS TOTAL
Course Required	2	8	10
Course Not Required (Training sessions only)	2 (grad)	2 (undergrad)	4
PARTICIPANTS TOTAL	4	10	14

Table 6: Participants in the study.

The participants' teaching experience ranged from none to four semesters, although most were teaching laboratory or recitation sections for the first time concurrently with the course. One participant had previously taught a course independently. Others had taught laboratory sections or recitations. Many had been tutors as undergraduates. They had not had any formal instruction on how to teach. A few had attended the University's two-day introduction for new TAs. They indicated their level of interest in teaching as low to moderate.

3.3.2 Recruitment and selection of expert group

In addition to the study participants in the course, four experts who were not in the Department were asked to answer the written measures. These four did not take pre- and post- tests but rather took each measure only once, providing a contrast group to the teaching assistants. "Expert" in this case was a label given to these individuals on the basis of their professional experience: three had been physics teachers in secondary schools for several years with two of them simultaneously pursuing a PhD in science education, while the fourth was a PhD physicist who was working full-time in PER. The four experts volunteered their time and were not compensated.

3.4 THE TRAINING SESSIONS

The first training session focused on forces, in particular the analysis of forces in a static equilibrium scenario. The second session targeted work-energy problems involving friction which is typically (implicitly) classified as doing external work on the system in question. The third session dealt with two equivalent approaches to scenarios involving extended objects and torque, again in static (rotational) equilibrium. The activity sheets for the training sessions are provided in Appendix A.

3.4.1 Forces

A very common and seemingly simple scenario in which a book is at rest on a level tabletop was chosen to initiate the first training session. The TAs were asked to consider various transcripts of student discussions about the forces acting on the book in this case. The transcripts varied in the extent of student-TA interaction, but each one challenged the assumed TA expectation that explaining the interaction between the table and the book in terms of a force is unproblematic. In small groups the TAs answered a series of questions about the scenario, which they shared with the whole group on white boards. The session ended with the whole group reflecting on the use of the bridging analogies, and more generally considering the role that students' prior knowledge plays during instruction.

3.4.2 Energy

This second training session centered on the use of energy bar charts as a representational tool to help students understand the transformation of energy from one type to another. The scenario presented to the TAs for the energy training session was also a very common one, and seemingly unproblematic: a car skidding on an uphill road with friction comes to a stop. The problem involved enough types of energy to showcase the use of energy bar charts. Again, the TAs first worked in small groups through different hypothetical student-TA recitation interactions. This small-group work was subsequently shared with the whole group on white boards, with the final reflection centering on students' challenges with energy problems and the role of energy bar charts in overcoming those challenges during recitation.

3.4.3 Torque

In the third training session the focus was on two equivalent formulations of torque in the context of a static rotational equilibrium scenario, with the assumption that TAs may be familiar with one or the other but not both. A scenario involving an outstretched arm holding a gallon of milk provided the context for talking about forces, lever arms, and torques. One representational approach involved drawing the lever arm as the length of an abstract line that is perpendicular to both the line of force and a line passing through the axis of rotation. The other approach defined the lever arm as the physical extended object (the arm in the scenario). A clear understanding of the equivalence of these ways of calculating the torque (with the appropriate definition of the force involved) would provide the TAs with the ability to understand students' perspectives on such scenarios, since different students are likely to use one or the other approach.

In this case, too, TAs worked through the torque problem, first by themselves and then in small groups, paying attention to articulating their approach explicitly. Mock transcripts between students and TAs were provided, which formed the basis of discussions about the utility of understanding both approaches while teaching recitation.

3.5 DATA SOURCES

This subsection discusses the data sources used in this study. The different sources address the impact research questions as shown in Table 7. This and the following subsection are organized by the data sources, while the discussion of the results is organized by the three training sessions.

Data Sources	Participants			Impact Research Questions	
	TAs	Class	Experts	#1	#2
Global Pre/Post	●	●	●	●	
Pre/Post 1	●	●	●	●	
Post Post 1 Assessment	●	●		●	
Pre/Post 2	●	●	●	●	
Post Post 2 Assessment	●	●		●	●
Pre/Post 3	●	●	●	●	
Questionnaire	●	●	●		
FCI	●	●			
Observations	●			●	●

Table 7. Data sources. Dots indicate the participants and the research question associated with the source.

The bulleted list below shows a timeline of the data collection for the *TA* and *Class* participants. Data were collected during the fall term of 2007. The experts were given the measures indicated in Table 7 at one time near the start of the study.

- Questionnaire
- FCI
- General pre-assessment
- **Training Session 1 (Sept. 14, 2007)**
  - Pre-assessment 1
  - Post-assessment 1
- Observations
- **Training Session 2 (Sept. 28, 2007)**
  - Post post 1
  - Pre-assessment 2
  - Post-assessment 2
- Observations
- **Training session 3 (Oct. 19, 2007)**
  - Post post 2
  - Pre-assessment 3
  - Post-assessment 3
- Observations
- General post-assessment

3.5.1 Pre- and Post-assessments

There were four pre- and post-assessment pairs, a global one that enveloped all of the training sessions and three local ones that enveloped specific training sessions. The three local pre- and post-assessments pairs were specifically designed to capture changes in knowledge due to the training sessions. The designs of these three as well as the global pre- post-tests were informed by PER and educational research specifically focusing on pedagogical content knowledge. In addition there were two later post-tests; the first later post-test was given at the start of the second training session and the second one was given at the start of the third training session.

Each assessed material from the previous session. Experts took these measures only once, not as pre- and post-test pairs. Also, they did not take the post post-tests.

3.5.2 Standard measure

The Force Concept Inventory or FCI (Hestenes, Wells, & Swackhamer, 1992) was only administered to participants once at the start of the study. It is a standard measure developed to test understanding of Newtonian mechanics. It was used to establish the baseline physics content knowledge of the participants in the study.

3.5.3 Questionnaire

The questionnaire (see Appendix E) asked participants about their previous education in physics, their previous teaching experience, and their level of interest in teaching physics.

3.5.4 Observations

The four TAs participating in the study were observed while teaching recitations throughout the fall semester of 2007. The observations were documented by audiotapes of the recitations and field notes which captured the TAs' board work. The audiotapes were later transcribed.

The observations took place during either PHYS 0110 or PHYS 0174 recitations, the algebra- and calculus-based introductory classes, respectively. Approximately 20-25 students attended each recitation, except for one TA whose recitation had about 60 students. The recitations focused on problem-solving, which meant that TAs were instructed to work problems on the board, whether from homework, their own invention, or quizzes and exams. One used a unique format in which students first presented their solutions, and then the TA guided the class through the solution after it was displayed.

3.6 DATA ANALYSIS

Across all the data sources the sample selection unit of analysis was an instructional episode, which was clearly defined on the written measures: each measure presented a single scenario, within which specific questions referring to the scenario counted for a single instructional episode. In TA observations, instructional episodes were delineated by 1) reference to a given problem, and 2) a change in representational type. For example, if a force problem was solved entirely using math (mathematical representation), it was counted as a single instructional episode. If the TA started the next problem using math, it was counted as a separate episode. And if the TA switched from math to a free body force diagram within a problem, it was counted as a separate episode.

All of the qualitative data were coded using coding rubrics (or matrices) that focused on representations, problem solving strategies, and questioning strategies. The rubrics were designed to reflect the categories of interest within TAs' practice as detailed in the previous chapters. Similar rubrics were applied to all of the data except for the FCI, which has its own analysis procedure yielding quantitative data, and the questionnaire, which provided background information. In the following subsections the data analysis is discussed source by source in the same order as in the previous section.

3.6.1 Pre- and Post-assessments

As detailed in the previous chapter, there were four (4) pairs of pre- post- assessments, one for each training sessions and one that enveloped all three sessions. Also two additional post-assessments were administered, one to assess forces (called “post post 1” and administered during the work-energy training session) and one to assess work-energy (called “post post 2” and administered during the rotational motion training session). Each assessment was analyzed for whether or not items within the categories were present using a rubric that explained each representation as shown in Table 4. For example, if a participant used a free body diagram in an explanation, this was indicated as an instance of use within the category of representations. An example of the application of the pre- post- assessment rubric is provided in Appendix A.

3.6.2 Standard measure

The FCI has an accompanying answer sheet that was used to score the measure. The threshold for expert competency is 85% correct answers.

3.6.3 Questionnaire

The questionnaire only provided general background information such as prior teaching experience or teacher training. There was no analysis performed.

3.6.4 Observations

Of the group of fourteen students who attended the trainings, four were subsequently observed teaching recitations. Audio recordings along with field notes comprised the data from the observations of the recitations. The transcripts of the recordings were complemented by the figures the TAs drew on the board as noted in the field notes. The transcripts were formatted as spreadsheets to facilitate the coding in which each line contains a phrase or short statement. Phrases were decided upon by listening for natural breaks in the audio recordings. The splitting of the transcript into phrases was just for convenience. As a result of the coding scheme the transcript was not coded at the level of phrases but at the level of instructional episodes. Each assigned code defined an episode which changed when the next code was assigned.

The procedure for applying the categories was refined with the help of Dr. Robert Hausmann, a postdoctoral researcher at LRDC at the University of Pittsburgh. Both he and I applied the categories to sections of the transcripts and then we checked for consistency between us. Once Hausmann and I had consistent agreement, I explained the categories and the coding procedure to a graduate student in the physics department who independently coded greater than 20% of a random sampling of the transcripts. Intercoder reliability, quantified by the parameter kappa (Newman & Kohn, 2007), is the extent to which two independent coders evaluate the same transcript and reach the same conclusion. Kappa equals the ratio of two differences as shown in Figure 4. The numerator is the difference of the actual agreement between the two coders and their expected agreement. The denominator is the difference between one (1) and the expected agreement between the two coders.

kappa = (actual – expected)/(1 – expected)

Figure 4: Calculating kappa.

The expected agreement is itself a ratio. The numerator is the sum of the products of each coder's number of codes for a each category. The denominator is the square of the total number of assigned codes.

The agreement between the reliability coder and me exceeded a standard threshold range of 0.70-0.80, as shown in Table 8. After establishing our agreement, I coded all of the transcripts producing the results in Chapter 4.

1. The audio recordings were transcribed.
2. Representations were added from field notes to produce the final transcripts.
3. The coding categories were used to code the data through the application of rubrics.
4. Categories included:
    a. Representations
    b. Force Problem Components
    c. Energy Problem Components.
5. The reliability coder coded more than 20% of the transcripts.
6. The number of codes for each type was totaled.
7. Representations:
    a. An episode is defined as an unbroken assignment of a single code.
    b. Kappa was calculated for the number and types of episodes present.
        i. Kappa = 1.00
    c. Kappa was calculated for the sequence of episodes.
        i. Kappa = 0.92
8. Force Problem Components:
    a. Kappa was calculated for the presence (and/or absence) of codes.
        i. Kappa = 0.89
9. Energy Problem Components:
    a. Kappa was calculated for the presence (and/or absence) of codes.
        i. Kappa = 0.76

Table 8: Procedure for coding of observations with calculated kappa

All disagreements between the independent coder and I were quickly resolved by discussion; they usually hinged on a mention of a term without context. For example, whether or not an isolated mention of “diagram” should be coded as a diagram or a picture or both.

CHAPTER 4: RESULTS

The results address the impact research questions with a focus on: 1) representations, and 2) problems solving steps. They include session data from the written measures and observations as well as aggregated data to highlight trends.

As a starting point, I consider the FCI, a standard test of conceptual knowledge of introductory Newtonian mechanics. A score of 85% is considered to be the expert threshold. The average score of all the participants was 91%. Only three participants scored below the expert threshold as shown in Table 9, and none below 80%. This result confirms the assumption that TAs possess a high level of subject matter knowledge.

FCI Scores	TAs	Class
Above 85%	4	7
Below 85%	0	3

Table 9. FCI Scores of TAs and Class participants.

4.1 FIRST IMPACT RESEARCH QUESTION – REPRESENTATIONS

The first impact research question was: did the training session on multiple representations change the TAs' use of representations? The following subsections answer the question session by session using the results of the written measures and the recitation observations. The written measures used are provided in Appendix A.

4.1.1 First training session

Table 10 shows that the participants did not increase their use of analogies after the training session. In answer to a question which asked them to explain the normal force to a student who was confused about the concept (see Appendix A), "Demo" was the predominant representational type mentioned by the *TAs* while "None used" most frequently characterized the responses given by the participants in the *Class* group. The experts used a variety of representations fairly equally.

Representation	Percentage Session 1 - Forces				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
None used	0%	0%	40%	50%	25%
Math	0%	50%	20%	20%	50%
Graph	0%	0%	0%	0%	0%
Picture	25%	25%	0%	0%	25%
Analogy	25%	25%	0%	0%	0%
Demo	100%	75%	20%	10%	0%
F.B.	0%	0%	10%	0%	50%
Ext. F.B.	0%	0%	20%	20%	25%
En. Chart	0%	0%	0%	0%	0%

Table 10: Assessment of the first training session.

However, the results from the post post 1 assessment (see Appendix A for the assessment) given two weeks later indicated that the majority of the participants chose to use multiple representations to explain the normal force, as shown in see Table 11. Participants were again asked to explain the normal force using three possible representations that were provided. Not only did the participants employ these representations, half of them explicitly mentioned "deformation," a concept central to the bridging analogy used in the training session.

Normal Force	**Percentage Post Post 1**		
	TAs	**Class**	**TA & Class**
Diagram(s) Used			
a	75%	90%	86%
b	75%	80%	79%
c	50%	30%	57%
Deformation			
Yes	50%	50%	50%
No	50%	50%	50%

Table 11: Delayed assessment of the first training session.

An analysis of the transcripts from the recitation observations shows that TAs relied primarily on mathematical representations, as can be seen in Table 12. They also frequently used pictures and diagrams. Some of the representational types such as energy bar charts are not relevant to the first training session.

Representations Used During Recitation	**Force Problems**
None	Never
Math	Always
Graph	Never
Picture	High
Analogy	Never
Demo	Never
F.B.	High
Ext. F.B.	High
En. Chart	Never

Table 12: Recitation observations after the first training session. Energy bar charts are not relevant to the first training session.

4.1.2 Second training session

Table 13 shows the results of the assessments taken before and after the second training session which asked for a strategy for helping students with work-energy problems (see Appendix A). They reveal that the participants employed the energy bar chart in the post-assessment at high levels. Experts relied on pictures and energy bar chart equivalents. (One expert described an energy bar chart equivalent demonstration in which students moved marbles among cups which represented the different types of energy.)

Representation	Percentage Session 2 – Work/Energy				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
None used	50%	0%	0%	0%	0%
Math	0%	25%	50%	10%	50%
Graph	0%	0%	20%	10%	0%
Picture	25%	75%	60%	40%	75%
Analogy	0%	0%	0%	0%	25%
Demo	0%	0%	0%	10%	0%
F.B.	25%	25%	30%	30%	0%
Ext. F.B.	0%	0%	50%	30%	25%
En. Chart	0%	75%	10%	80%	50%

Table 13: Assessment of the second training session.

Table 14 shows how participants classified the problem on the pre- and post- assessments; classifying it as a force problem would be unlikely to lead to the use of a representational tool designed for energy problems.

Problem Type	Percentage Session 2 - Work/Energy				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
Force	25%	0%	50%	20%	25%
Energy	25%	100%	50%	80%	75%
Other	50%	0%	0%	0%	0%

Table 14: Problem type assessment of the second training session.

Table 15 refers to the post post 2 assessment (see Appendix A for the assessment), given three weeks after the second training session, in which TAs were asked to construct an energy bar chart for a given problem. Although participants uniformly recalled the instructional tool, they strikingly failed to unambiguously define the system, thus omitting a step that is a crucial prerequisite to the use of the energy bar chart.

Energy Bar Chart	**Percentage Post Post 2**		
	TAs	**Class**	**TAs & Class**
Recall	100%	100%	100%
System	0%	20%	14%

Table 15: Delayed assessment of the second training.

The scenario on this assessment clearly involved friction (see Appendix A), yet only two participants explicitly identified defining the system as the deciding factor whether or not friction is counted as work. Furthermore, among the twelve participants who did not explicitly identify defining the system as the key, many offered incorrect reasons for why friction is to be counted as doing (external) work on the system. Table 16 shows participants' responses to the question on the post post 2 assessment.

Question: *Is the frictional force represented as doing work in your energy bar chart?* • *If so, why? (That is, how did you decide to include it as work?)* • *If not, why? (That is, how did you decide not to include it as work?)*
1. Yes because every force might be associated with some work and we can use W=F•d•cosθ to decide the work done by frictional force is W=F•d•cos180, not 0, so we have to include it for the W-E theorem.
2. I forget how these things are represented. But the frictional force should be included as work.
3. Yes. The frictional force stops you, so it does lots of negative work.
4. Yes. Friction does work on the system. And it is non conservative force.
5. Yes. Friction just transfer the kinetic energy into heat, in the form of doing work.
6. I include it b/c I consider the friction to "change the energy" in the system. Without being too technical (it's been a while), it's external.
7. Because this is one of the forces which stops the car. A=**F•r**
8. Yes. Friction is non-conservative.
9. Yes, it is acting over the distance it takes the car to stop.
10. Yes. Frictional force is the only external force. So it is included (and is the only one included).
11. Yes, because it is being done by an external entity (the system is the car only).
12. Yes, I decided to keep Earth as part of the system for the purpose of gravitational PE, but considered the road as outside the system, so that it could remove energy from the system.
13. Because force due to friction and the corresponding displacement is given.
14. Yes, but the work is negative, implying that it's the car doing the work (negatively) because I don't think frictional forces can "do work."

Table 16: Participants' answers to a question about a work-energy problem. The first four are the TAs.

In the recitation observations during that period, shown in Table 17, the energy bar chart representation was used only once. Its use, however, was not supported by the associated problem solving steps, which resulted in an ambiguous assignment of energy types depicted on the energy bar chart. Mathematical representations again dominated, followed by pictorial representations.

Representations Used During Recitation	Energy Problems
None	Never
Math	Always
Graph	Never
Picture	High
Analogy	Never
Demo	Never
F.B.	Some*
Ext. F.B.	Never
En. Chart	Low**
*Two-part problems that start with a force problem **One observation	

Table 17: Representations used during recitations on energy problems.

4.1.3 Third training session

Table 18 shows that the third training session resulted in an increase in the use of free body force diagrams and extended free body diagrams (see Appendix A for the assessment). In this case the scenario showed a picture of a block hanging from a rod in static equilibrium. The measure asked the participants to indentify potential student difficulties and to provide a strategy of overcoming the difficulties. While both experts and participants relied heavily on mathematical representations, beyond that they chose different avenues. Demonstrations are clearly on the radar of the experts. One of them wrote, "I could demo balancing a meter stick…" or "[The] student holds [the] meter stick at one end and I push (or hang masses) at [the other] end, [the] middle, [and] close to the hand, each time with [the] same force." In contrast to the experts, the participants did not turn to demonstrations. They stressed the mathematics instead. One TA wrote: "Maybe go through [the] concept of torque again. Make them understand 'sinθ' term in equation is there to take the component of normal to lever arm. Show how to use equation." Pictures also were important to experts but used very sparingly by the participants.

Representation	Percentage Session 3 - Torque				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
None used	75%	25%	40%	20%	25%
Math	25%	25%	30%	50%	50%
Graph	0%	0%	0%	0%	0%
Picture	0%	0%	10%	0%	50%
Analogy	0%	25%	0%	0%	0%
Demo	25%	0%	10%	0%	50%
F.B.	25%	50%	20%	50%	0%
Ext. F.B.	0%	25%	0%	30%	0%
En. Chart	0%	0%	0%	0%	0%

Table 18: Assessment of third training session.

4.1.4 Global pre- post-assessment

The results of the global assessment (see Appendix A) that enveloped all three training sessions are shown in Table 19 and Table 20. This assessment contained two scenarios, each of which asked participants to explain concepts to students which were potential areas of difficulty. They show no real change in the use of representations besides some increase in the use of free body force diagrams.

Representation	Percentage Global – part 1				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
None used	50%	75%	60%	20%	50%
Math	50%	25%	30%	30%	25%
Graph	0%	0%	0%	0%	0%
Picture	0%	0%	0%	0%	0%
Analogy	0%	0%	0%	0%	0%
Demo	0%	0%	0%	0%	0%
F.B.	0%	0%	20%	70%	25%
Ext. F.B.	0%	0%	0%	0%	0%
En. Chart	0%	0%	0%	0%	0%

Table 19: General assessment pre- and post- all three training sessions, part 1.

Representation	Percentage Global– part 2				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
None used	0%	25%	60%	75%	50%
Math	75%	25%	10%	25%	25%
Graph	0%	0%	0%	0%	0%
Picture	0%	0%	10%	0%	0%
Analogy	25%	0%	0%	0%	25%
Demo	0%	0%	10%	0%	50%
F.B.	50%	50%	10%	50%	0%
Ext. F.B.	0%	0%	0%	0%	25%
En. Chart	0%	0%	0%	0%	0%

Table 20: General assessment pre- and post- all three training sessions, part 2.

4.1.5 Summary

Table 21 shows the percentage of representation use across all instances of representation use on the written measures.

Representation	Percentage Totals				
	TAs		Class		
	Pre	Post	Pre	Post	Expert
None used	28%	17%	31%	18%	18%
Math	24%	21%	22%	18%	24%
Graph	0%	0%	3%	1%	0%
Picture	8%	14%	12%	6%	18%
Analogy	4%	7%	0%	0%	6%
Demo	20%	10%	6%	3%	12%
F.B.	16%	17%	14%	31%	9%
Ext. F.B.	0%	3%	11%	12%	9%
En. Chart	0%	10%	2%	12%	6%

Table 21: Pre- and post- assessment totals.

Table 22 highlights that mathematical and free body force diagrams are the most heavily used representations. “None used” was also invoked many times.

Representation	Percentage Totals		
	TAs + Class		Expert
	Pre	Post	
None used	30%	19%	18%
Math	22%	20%	24%
F.B.	14%	29%	9%
Other	34%	32%	50%

Table 22: Pre- and post- assessments totals highlighting the predominant types of representations.

Table 23 shows the use of representations immediately after the training sessions, two to three weeks after the sessions (post post assessment), and during observations. Both post post results show that the strategies in training sessions 1 and 2 were recalled weeks after the sessions. But neither case led to the use of the strategies in the subsequent recitations.

Representations	Global	Training Session		
		1	2	3
Immediate post-assessment	Low or None	Low or None	High	Medium
Post post assessment	n/a	High	High	n/a
Recitation observations	n/a	Low or None	Low or None	Low or None

Table 23: Use of representations by TAs.

4.2 SECOND IMPACT RESEARCH QUESTION – PROBLEM SOLVING STEPS

The second impact research question asked: did TAs rely on the problem solving steps explicitly outlined in the training sessions to support the use of representations? The following discussion answers the question using the results of the written measures and the recitation observations.

Table 24 and Table 25 show the usage of problem solving steps in force and energy problems, respectively. The use of a component might refer to a simple comment or an extensive discussion or anything in between. In any case it is striking to note that in the recitations the "System" component was not observed. For the force problems, this is not too critical in the sense that there is usually one object under consideration, leading to an implicit identification of the object as the system. While this is typically true of work-energy problems as well, in these problems designating the types of energy involved is crucially dependent on defining the system, even in cases where there is only one primary object.

Components Used For Force Problems	
Principle	Low
System	Never
Motion	Always
Forces	Always
Origin	High
Axes	High

Table 24: Components used during recitations involving force problems.

Components Used For Energy Problems	
Principle	Always
System	Never
States	Always
Types	Always
Work	Always
Ext. Forces	Always
Axes	Never

Table 25: Components used during recitations involving energy problems.

In an illustrative example of the confusion created by not consistently defining the system, Table 26 lists the multiple ways work was defined in a single problem. The transcript is provided in

Appendix B. Note that the TA also advocates a "plug and chug" method for solving problems in lines 57-58, indicating that this would be the preferred way to solve the problem.

Line	Phrase	System
8	energy stored	block & spring
26	work done by spring	block
30	in this system	???
32	energy loss	block & spring?
39	work done by spring & friction	block
47	potential energy & work done by spring	???

Table 26: Ambiguous definitions of the system.

Other TAs also discuss the work done by gravity at the start of a problem, and by the end were talking about the gravitational potential energy. The TAs were not explicit about the system nor were they consistent regarding their implicit choice.

4.3 CONCLUSIONS

The most striking pattern was that the pre- and post-assessment measures indicated that TAs' knowledge of the strategies increased after the training sessions while the recitation observations showed no evidence of the strategies. Other patterns include that TAs:

- Relied on mathematical representations
- Focused on rote problem solving procedures
- Struggled with knowing the implications of defining the system on energy types
- Sequenced representations in math, non-math, math patterns (mathematical representations book-ending all other types).

CHAPTER 5: DISCUSSION

While the observations discussed in the previous chapter provide answers to the *impact* research questions, they call for an analysis at a deeper level. I argue that the observed trends can be explained in terms of the TAs' subject matter knowledge, the left hand side of Figure 1 which is repeated below in Figure 5 for reference.

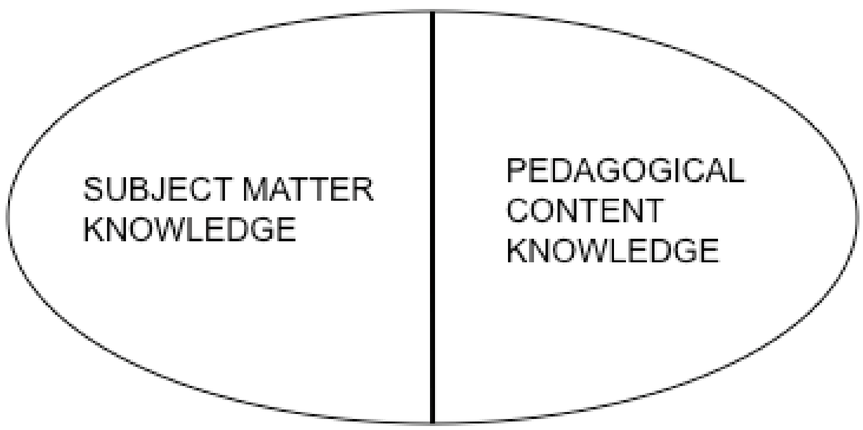


Figure 5: Two types of *knowledge for teaching* (from Ball et al., 2008, p. 403).

What conclusions about TAs' *knowledge for teaching* can be drawn from the aforementioned trends? And what role does subject matter knowledge play? Ball et al. (2008) have convincingly used knowledge for teaching as an analytical lens to investigate the unique knowledge that practicing teachers use in their daily teaching, especially subject matter knowledge. Asking questions about subject matter knowledge reexamines the assumption that as physics graduate students the TAs have adequate knowledge of physics to teach an introductory course. Such knowledge plays a crucial role in the TAs' ability to implement the strategies that were stressed in the training sessions. With this in mind, I will address a second pair of research questions which are stated in Table 27.

Knowledge Research Questions 3. *What knowledge for teaching do physics graduate TAs possess or lack?* 4. *Can this knowledge for teaching be classified consistently into empirically generated categories in harmony with the typology of Ball et al. (2008)?*

Table 27: Research questions investigating TAs' knowledge for teaching.

The first knowledge question looks specifically at the TAs in the study. Most of the time the TAs' knowledge meets the needs of teaching recitation. There are moments, however, when TAs' lack of knowledge generates confusion or leads to missed opportunities for student learning. The second knowledge question speaks to the robustness and generalizability of the categories of knowledge for teaching. Ball and her colleague draw on evidence from elementary mathematics teachers. If their map is to be useful beyond their specific research program, as they claim, instances from other content matter areas should align with their findings.

5.1 REFINING SUBJECT MATTER KNOWLEDGE

Many research efforts over the last two decades have targeted the refinement of aspects of pedagogical content knowledge (PCK). Recently efforts have shifted from investigations of theoretical knowledge constructs to empirically driven studies aiming to clarify the constructs

(Ball et al., 2008; Hill, Ball, & Schilling, 2008). This has led to efforts to elaborate on PCK, the right hand side of Figure 5, in new ways. In Hill et al. (2008) the authors posit that there are presently two key issues why PCK remains unspecified: first, not enough empirical research has been done to establish PCK as different from subject matter knowledge; and second, there has been a lack of well developed, validated, and published measures of PCK (p. 373). While stating that these two points by themselves merit investigation, Hill and her collaborators additionally argue that these missing pieces hinder connecting knowledge for teaching with student achievement; although the two are theorized to be connected, they have not been shown to be related through large-scale studies (p. 373). Their own 2005 study, in which knowledge was ambiguously defined, has since been designated as study on specialized content knowledge, not PCK. While these two avenues of research merit attention, the focus in this dissertation is on subject matter knowledge.

During the past couple of years, Ball, Hill, and their colleagues have also used empirical investigations to elaborate on subject matter knowledge. Their research points to at least two subdomains of subject matter (or domain content) knowledge. Though Shulman (1986a) made an initial attempt at parsing teachers' subject matter knowledge *per se*, stating that the "teacher need not only understand *that* something is so; the teacher must further understand *why* it is so" (p. 9), most of the subsequent attention focused on PCK. Differentiating subdomains requires empirical investigation in order to establish their existence and boundaries. In Figure 6 the subject matter knowledge portion of Figure 5 is divided into two previously undifferentiated subdomains, common content knowledge and specialized content knowledge (Ball et al., 2008).

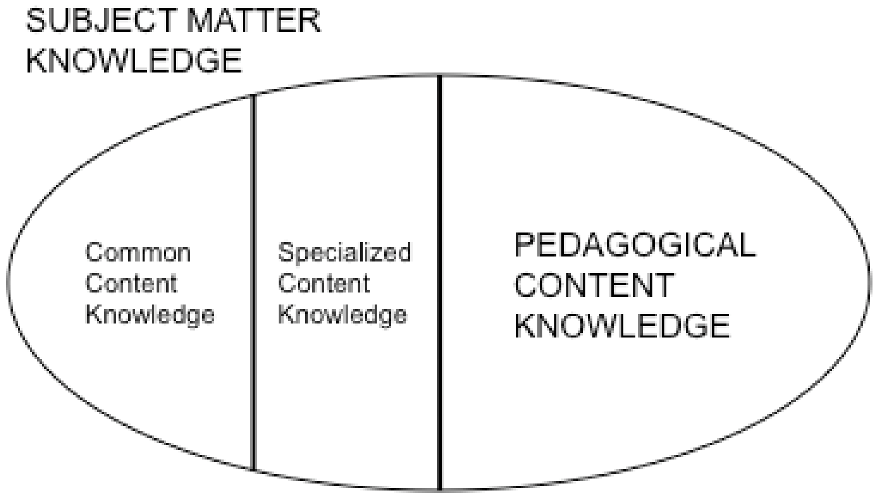


Figure 6: Refining subject matter knowledge (adapted from Ball et al., 2008, p. 403).

Common content knowledge is knowledge that both non-teachers and teachers alike possess. Graduate students actively develop their common content knowledge, that is the knowledge that is shared among physicists. (The term “common” does not mean that the knowledge is commonly held by people of all walks of life, but that it is common to physicists.) For example, knowing that the work done by an external force on an object can be calculated by taking the scalar product between the force and the displacement vectors is considered common content knowledge in physics. I use the abbreviated term “common knowledge” to label knowledge that is not specific to those who teach.

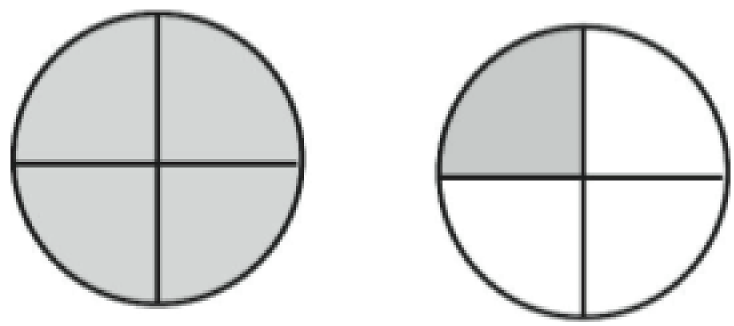


Figure 7: Representation of a fraction of 2.

On the other hand, specialized content knowledge is "special" because it is knowledge that teachers alone possess. This difference can be illustrated with an example from the Ball et al. article (p. 403): is the knowledge that the shaded portion in Figure 7 represents 5/8 of 2 common or specialized? They conclude that it is specialized because non-teaching users of mathematics do not need to draw on such knowledge, while teachers rely precisely on such knowledge as they teach. Mathematics teachers realize that students struggle with fractions of the whole. In this case 2 is the whole, and considering 5/8 of 2 provides students with an opportunity to explicitly encounter a potentially difficult concept. In physics, knowing how to solve a problem two different ways, with the system defined differently in each counts as specialized content knowledge because scenarios that require such knowledge typically occur while teaching physics. Also, knowing that when calculating the torque that a force exerts on an object (without using a vector product) one can use the magnitude of the force vector or the magnitude of the component of the force vector perpendicular to the lever arm, depending on how the lever arm is defined, seems to be relevant mainly when teaching physics. I use the abbreviated term "specialized knowledge" to label knowledge that is specific to those who teach. The investigations described in this dissertation focus on specialized knowledge. (The authors (Ball et al., 2008) actually suggest three subdomains of subject matter knowledge, but the third one is not relevant to this discussion.) Ball's group recognizes it is at times not easy to distinguish between common and specialized knowledge, but the distinction is a valuable heuristic (p. 403).

5.2 THE ROLE OF SPECIALIZED CONTENT KNOWLEDGE

The design of the training sessions within the present study relied on bringing best practices from PER into a PCK framework, as discussed in the previous chapters. The design approached the relationship between subject matter knowledge and PCK as unproblematic. No attempt was made to define subdomains within subject matter knowledge, nor was there an articulated connection between the two sides of Figure 5 beyond the assumption that graduate TAs had the requisite subject matter knowledge to teach recitations for introductory physics courses. The training sessions focused on different representations as pedagogical tools assuming the TAs had the requisite content knowledge.

When analyzing the results of the study it became apparent that the representations offered in the training sessions, while understood by the TAs at the time, were not finding their way into the TAs' classrooms. More specifically, the pre- and post-assessments used in this study indicated that the training had an immediate impact on the TAs' knowledge of the training session topics. Beyond this short-term effect, the post-assessments a few weeks after the training sessions (post post 1 and post post 2) showed that the TAs had retained the knowledge through the time period when they taught the recitations addressing those topics. Yet the analysis of the recitation observations showed that the TAs did not utilize this new knowledge in their teaching.

Based on this new evidence an additional component of knowledge appeared to be lacking, a component which might have enabled the implementation of the strategies. The strategies that were thought to be sufficient if they targeted only PCK, in fact had to target both PCK and specialized knowledge. Furthermore it suggests that PCK cannot be isolated as such, but always relies on some aspect of specialized content knowledge. While separating the two may be a valuable heuristic for making progress in characterizing teachers' classroom practices, on closer inspection the line between them is fuzzy.

The answers to the knowledge research questions challenge the assumption of the adequacy of the TAs' subject matter knowledge in the spirit of Ball et al. (2008) by: 1) parsing subject matter knowledge into subdomains, 2) unpacking the connection between the subdomains and PCK, and 3) providing evidence that at times specialized knowledge was lacking. They also challenge the rigid separation of pedagogical content knowledge and specialized content knowledge.

5.2.1 Findings from this study regarding work-energy problems

The strongest evidence of the critical role of specialized knowledge comes from examining the TAs' teaching of work-energy problems. As stated, they did not use the powerful tool of energy bar charts in their teaching of recitations. Accompanying the charts was a sequence of problem solving steps that included defining the system in the problem. Designating the system versus the surroundings is an abstract and arbitrary step, but an absolutely necessary one for consistently applying subsequent steps. In energy problems (see Table 28) the steps "System," "States," "Types," and "Work" are all needed to generate an energy bar chart. Furthermore, these four steps are interdependent and contingent upon the first step, "System," for consistency.

Component	Definition
Principle	Articulates energy principle(s) that frame(s) the problem
System	Chooses/defines a system
States	Characterizes initial state and final state
Types	Identifies types of energy (or how they transform)
Work	Decides if work is done
External Forces	Identifies external forces
Axes	Defines coordinate axes

Table 28: Components of solving work-energy problems.

The recitation observations revealed that TAs consistently addressed only two of the steps, importantly omitting "System" as shown in Table 29.

Steps used by TAs	Steps not used by TAs
Types	Principle
Work	System
	States
	External Forces
	Axes

Table 29: TAs' use of problem solving steps.

Some "Type" of energy is often the goal of *solving* energy problems. If a problem calls for the value of a calculation of a form of energy, then the "Types" step is met. Likewise there is often a calculation of the work involved in solving problems, sometimes involving using a force as step prior to finding the energy, thereby satisfying the "Work" step. The steps that TAs did not use were steps that are not often explicitly needed in *solving* problems but are crucial to *teaching* problems. Thus not only does solving problems stress only two steps, "Types" and "Work," but the answers to the problems typically only ask for information contained in those two steps.

These two steps do not provide enough information to generate an energy bar chart as this tool requires explicit attention to all of the steps. Observing the TAs' difficulties with consistently defining the system, I designed post post 2 in order to investigate the TAs' knowledge of this important step.

As shown in Table 30, while all of the TAs recalled the energy bar chart, none of them defined the system in a manner that would enable its use. These results validated the confusion TAs exhibited in recitation concerning this issue (see transcript in Appendix B).

Energy Bar Chart	**Percentage Post Post 2**		
	TA	**Class**	**TA & Class**
Recall charts	100%	100%	100%
Define system	0%	20%	14%

Table 30: Delayed assessment of the second training.

These empirical results suggest that, in agreement with Ball et al. (2008), specialized knowledge is an important distinction within subject matter knowledge, one that enables access to the knowledge, skills, and strategies fundamental to PCK, as shown in Figure 8.

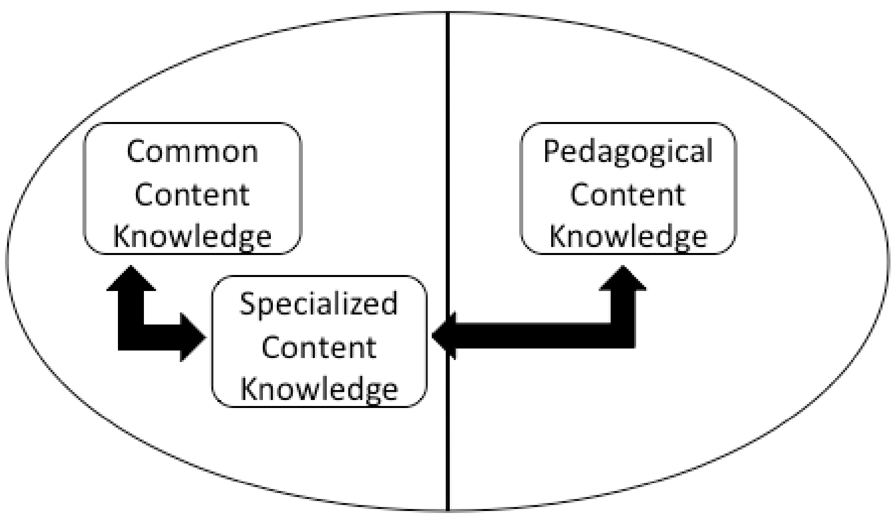


Figure 8: Specialized content knowledge connects common content knowledge and PCK.

Concretely, the TAs' lack of specialized knowledge regarding energy problems inhibited their ability to implement the PCK-based strategy of energy bar charts that was offered in the training session. As shown in Figure 9, the key missing link was the TAs' ability to define the system.

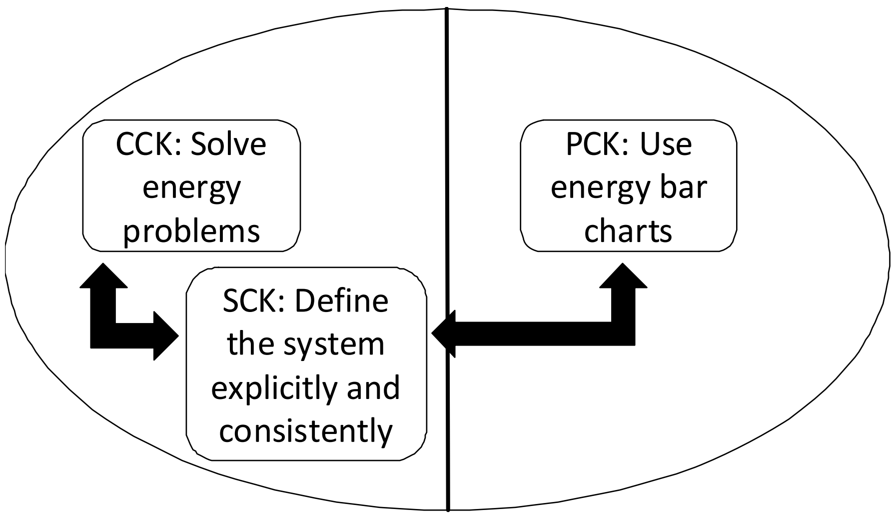


Figure 9: Specialized knowledge for solving work-energy problems.

5.2.2 Additional findings from this study

Additional findings shed light on the role of specialized knowledge. For example, during one observation the TA became aware that students were struggling with a rotational problem involving a person walking on a moving merry-go-round. As written, the problem suggested treating the person and the merry-go-round as a system, leading to a solution path based on the conservation of angular momentum. In an effort to help students understand the problem, the TA asked them to consider the merry-go-round alone as the system. The question then arose: what torque must the person exert on the merry-go-round in order to make it rotate faster? And the corollary question: what direction must the person walk in order to exert a torque on the merry-go-round to make it turn faster? The TA solved the problem as stated in the textbook (common knowledge).The TA also knew that the problem could be formulated either way, with the person being a part of the system or part of the surroundings (common knowledge). Additionally the TA knew that discussing both scenarios side by side might aid the students (PCK-based strategy). What was lacking, however, was the TA's ability to translate accurately between the two approaches (specialized knowledge). In the end the TA stated that the person needs to walk radially towards the center of the merry-go-round in order to exert the requisite torque, which is incorrect (the correct scenario would be considered common content knowledge). A radial force between the person's shoes and the merry-go-round does not result in a torque since the line of force passes through the fixed axis of rotation. Thus the TA's lack of specialized knowledge compromised the sharing of multiple problem solving strategies.

The notion of specialized knowledge as a bridge between common knowledge and PCK does not account for all of the results of the study, but it explains several striking examples of TAs' inability to capitalize on pedagogical strategies or tools. Table 31 lists several examples of the role of specialized knowledge, which were taken from the observations of the recitations.

Interestingly, findings from a study (Sink, Cartier, & Grabowski, 2007) of an NSF GK-12 project at the University of Pittsburgh showed that graduate students enhanced their content knowledge by way of knowledge of big ideas and connecting ideas across domains. The study supports the finding that teaching, in this case exemplified by the focus on big ideas, is enabled by subject matter knowledge.

<table>
<tr><th>Common content knowledge</th><th>Evidence of TAs’ lack of specialized content knowledge</th><th>Pedagogical content knowledge</th><th>Outcome due to lack of specialized content knowledge</th></tr>
<tr><td>Account for frictional forces, typically considered external (to the system) forces.</td><td>TA unequivocally states that the frictional force does work on an object.</td><td rowspan="3">Use of energy bar charts as an effective pedagogical tool.</td><td rowspan="3">TA avoids the use of the energy bar chart, or the TA translates the implicit system definition onto the chart thereby relegating the use of the chart to just another procedural step</td></tr>
<tr><td>Account for spring force.</td><td>TA states both that the spring force does work on an object and changes the potential energy of an object</td></tr>
<tr><td>Account for gravitational force.</td><td>TA states both that the gravitational force does work on an object and changes the potential energy of an object</td></tr>
<tr><td>Solve dynamics problem.</td><td>TA begins a problem of a block on an inclined plane as though the block is not moving; when a student correctly points out that the block is sliding at constant velocity; TA restarts the problem.</td><td>Highlight equivalent problem statements to facilitate students’ proper classification of problems.</td><td>TA misses an opportunity to highlight the equivalence of the set-up of the two scenarios thereby reinforcing students’ tendency to view each scenario as its own unique type</td></tr>
<tr><td>Understand moment of inertia of two similar shapes with different mass distributions.</td><td>TA fields students’ guesses comparing the moment of inertia of two similar cylindrical shapes and then calculates the moment of inertia for each shape.</td><td>Provide hands-on experience or connect scenario to prior knowledge.</td><td>TA misses an opportunity to highlight the idea of mass distribution while reinforcing students’ misconception that calculations are the primary mode of analyzing physical scenarios</td></tr>
</table>

Table 31: Mapping the role of TAs’ specialized content knowledge.

The emergence of specialized knowledge in two vastly different contexts – this study of graduate physics TAs and Ball et al.’s study of elementary mathematics teachers – confirms the robustness of the tentative subdomain of subject matter knowledge. In comparison to elementary mathematics teachers, physics TAs presumably have more subject matter knowledge, yet nevertheless they lacked specialized knowledge in some situations.

5.3 RECONSIDERING CONTENT KNOWLEDGE FOR TEACHING

All of Ball et al.'s (2008) proposed subdomains of knowledge for teaching refer to domain content. This suggests that there can be pure subject matter knowledge subdomains, such as common knowledge, but that there cannot be pure pedagogical content knowledge subdomains. In other words, each time a given aspect of PCK is examined, parts of the knowledge within the aspect will again be anchored in subject matter knowledge. The most fundamental conclusion – in keeping with Shulman's (1986a) missing paradigm – is that all knowledge for teaching is rooted to some extent in subject matter knowledge; it is the Archimedean fulcrum of teaching.

Ball et al. (2008) present an illustrative example in which a teacher is analyzing a student error. They offer that a teacher may pinpoint the error by 1) retracing the mathematical steps (specialized knowledge), or 2) recalling previous instances when students had made such a mistake (PCK) (p. 403). Logic dictates, however, that there was an initial instance when the teacher had to understand the mistake *per se* in order to trace the mathematical root of the error, Thus in either case content matter knowledge provides the key. This process is fundamental since all PCK is anchored in knowledge of the subject matter, whether common or specialized.

In an example from this study, knowing the problem solving steps for work-energy problems can be categorized as PCK, which is how I categorized it. But one of the steps calls for defining the system, and unless the TAs understand the connection of uniquely defining the system to the other problem solving steps they cannot effectively employ the steps. As in the example above, understanding each step and their connection is specialized knowledge. Although proof by example is not truly a proof, all the examples that occur to me have a component traceable to subject matter knowledge. It is my working hypothesis that all aspects of PCK contain some element that is classifiable in one of the subdomains of subject matter knowledge.

Experienced students can typically adjust for errors in energy problems by appropriately changing a plus sign or minus sign along the way, without concern for internal consistency. But the heuristic of changing a sign is unable to support the use of energy bar charts. There is evidence for several such informal methods which I call “procedural shortcuts.” Often the TAs avoid problematic or challenging scenarios that may require specialized knowledge by opting for shortcuts as shown in Table 32.

Scenario	Procedural shortcut
Solving a force problem	Manipulating equations with the comment “It’s just a bunch of steps.”
Solving an energy problem	Changing a “+” to a “–” in order to get the correct answer. TA states: “You could have essentially gotten by with just guessing a sign with 1/2 k x^2.”
Solving all types of problems	Reciting symbol by symbol what is written on the board with very minimal commentary. (See Table 33 below.)
Solving all types of problems	Using primarily mathematical representations.

Table 32: Shortcuts used by TAs.

Reciting symbol by symbol what was written on the board at times filled the recitation, as shown in the last six (6) minutes of the transcript in Table 33. (Line 269 is a student asking for mercy.)

211	19:40 Right, so it is mg cosine theta.
212	Because we drew the friction diagram here,
213	but this is mg, this is N, and this is friction force.
214	Since it is not moving into the surface or leaving the surface,
215	so mg cosine theta minus N should equal zero.
216	So this would be equal to mg cosine theta times mu k.

217 20:28 So now basically we have everything that we need.
218 So it's like 1 over 2 mv_0 squared would be equal to...
219 Okay if we add this on both sides this will cancel.
220 So 1 over 2 m v squared will be equal to
221 mg times d plus l_0 minus l sine theta plus...
222 1 over 2 k l_0 minus l squared
223 and then plus mg cosine theta mu k times d plus l_0 minus l.
224 So we have everything on the right hand side.
225 21:22 And another thing we can do now is check the dimension.
226 So on the left hand side it is...because m v squared is energy,
227 so it should have the dimension of energy.
228 So first we check the dimensions on the right side.
229 mg times l because cosine theta is dimensionless.
230 So the dimension of the term is kilograms,
231 and g is of the dimension of meters per second squared.
232 And d is of the dimension m.
233 So the dimension is kilograms times meters squared divided by seconds squared.
234 So that is the same as here...
235 so this term has the right dimension.
236 Hey, remember the dimension of k?
237 k should have the dimension so Newtons per meter.
238 l squared has the units of meters squared.
239 So this has the dimension of N times m and
240 remember that Newton is equal to ma...
241 one of the formulas is F equal ma.
242 m has the dimension of kg.,
243 a has the dimension of meters per second squared.
244 So if we plug the dimensions...here we have kilograms times meters per second squared
245 which has the same dimensions of this.
246 Okay?
247 And this term basically has the same dimension as this because mu k is dimensionless.
248 So this is consistent.
249 23:37 And also the dimension of energy is meters...is m times v_0 squared.
250 So this is kilograms times meters squared over seconds squared.
251 But also we know the equation for work equals force times distance.
252 So work also has the dimensions of force which is N times m.
253 So these are the two dimensions you want to use when you are taking the dimensions of energy...
254 24:15 So any questions regarding this problem?
255 So there may be different versions of this problem,
256 but this involves kinetic energy.
257 It involves gravity potential energy.
258 And spring potential energy.
259 And it involves friction.

260 *...noise...*
261 This might not be an incline.
262 It might be horizontal.
263 Then you don’t need to consider gravity energy.
264 Perhaps there is no spring at the end, so you don’t have to worry about spring energy.
265 Perhaps there is no friction, so you don’t have to worry about work done by friction.
266 But this problem involves all of the force and energy work you might use.
267 I wish this could be helpful for you when you are doing the homework for this week.
268 Okay, so any questions?
269 S: No.
270 No?
271 Okay, let’s do the quiz now.
272 25:30 THE END

Table 33: Transcript of TA discussing an energy problem.

The use of shortcuts amounts to the distinction between *solving* physics problems and *teaching* to understand physics through problems. Specifically focusing on representations, the list can be split into two categories: Those that TAs employ when solving the physics problems assigned as homework for themselves and those that TAs might use to teach how to solve the physics problems in recitation. TAs frequently used the *solving problems* column and rarely used the *teaching problems* column.

Used for solving problems	Used for teaching problems
Math	Graphs
Picture	Analogy
Free Body Force Diagram	Demo
Extended Free Body Diagram	Energy Bar Chart

Table 34: Representations used in problems.

Admittedly, this categorization is not perfect. Some TAs may have been able to solve some force problems without using free body force diagrams, yet they realized their importance in teaching.

But certainly using free body force diagrams makes solving problems with many forces easier. Clearly, the use of analogies is important for teaching the concepts in problems, but it is not needed for solving problems. The same is true for the use of demonstrations.

Considering problem solving steps, again some are necessary for *solving* problems while others are more important for *teaching* physics through solving problems. While in solving problems a physicist goes through many steps implicitly, teaching requires that all steps involved in solving a problem are made explicit.

Used for solving force problems	Used for teaching force problems
Motion	Principle
Force	System
	Origin
	Axes

Table 35: Problem solving components used in problems.

Recalling what the terms in Table 35 stand for, *motion* means that the motion of the object in the problem was targeted explicitly. *Force* means that the forces in the problem were targeted explicitly. Clearly these two steps are crucial for solving problems. Explicitly defining and targeting the principle used to solve a problem is not necessary as long as it is known implicitly. (One TA explained that stating the principle is confusing for students because they don't need it to solve the problem.) Also, in many problems there are natural choices for experienced problem solvers for the system, for the origin of the coordinate system, and for the orientation of the axes. Defining these is needed for teaching the concepts within the problems as well as teaching the skills necessary to become proficient problem solvers. Thus not only does solving problems stress only two parameters, *motion* and *force*, but the answers to the problems themselves typically only ask for information related to those two parameters.

Once the approach or direction for *solving* a problem is established, the rest of the effort consists of developing a step-by-step solution. TAs determine their approaches in private prior to recitation and use the recitation to go through their private solution step-by-step. Of course even after solving the problem, or especially after solving the problem, *teaching* physics by considering a problem requires making the reasons behind every step explicit. In this case questions would be used to probe student understanding, requiring open-ended discussion questions which allow for student explanations.

5.4 SUMMARY

In conclusion, understanding the map of knowledge for teaching proposed by Ball and her colleagues (2008) requires a pragmatic approach regarding the relationships between the subdomains. Specialized knowledge can be understood as both being directed at and supporting a strategy, a skill, or a representation in the PCK subdomain. For example, the use of a multiple representations strategy, as well as the representations themselves, can be categorized as PCK, but leveraging their features to teach a physics concept is specialized knowledge. Likewise, using appropriate problem solving steps is PCK, but understanding the purpose of and correctly executing each step is specialized knowledge.

CHAPTER 6: CONCLUSION

This final chapter addresses the limitations of this study and also speculates about next steps. It concludes with a short discussion of the type of questions that TAs ask during recitations which tentatively supports the argument presented in the previous chapter.

6.1 LIMITATIONS OF THIS STUDY

One limitation of the quantitative data in this study is the small number of TAs involved. However, in case studies like this one a deeper look with a large sample size is not possible. Only an in-depth study with a manageable number of participants made it possible to identify key issues, which can be used subsequently to inform the design of "big N" quantitative studies to investigate these issues. For example, the Force Concept Inventory is a multiple choice assessment in which the incorrect choices (distracters) have been purposefully chosen to match students' misconceptions. The design of the FCI depended on first identifying those misconceptions, which was done through detailed "small N" studies such as this one. Investigations into the knowledge for teaching are relatively new and for the time being rely primarily on case study type investigations.

Another limitation is that the TAs' attitudes towards the use of the strategies in the training sessions was not investigated. In addition to TAs' knowledge types, neutral or poor attitudes toward the use of the representations would clearly negatively impact TAs' practice. Professors Singh and Koehler have experienced negative attitudes of TAs towards imagining themselves as novice students of physics (personal communication).

A shortcoming of this study is that it did not directly measure the impact of TAs' knowledge on student learning. Studies making such a connection are surely needed but cannot be meaningfully undertaken until the impact of the training sessions on the TAs is more fully understood. Each step in the chain, from the sessions to the TAs' practice to the students' learning must be investigated in sequence in order to establish any connections (Smith, 2001). Once the connection between the training sessions and TAs' practice has been established, the students' performance in the recitations can be studied.

Finally, the interviews that I conducted only enter the discussion in this final chapter as information sources, not as data sources. This demotion of the status of the interviews is due to my lack of skill in conducting them in a uniform, standardized manner. Interviews have the potential to add a greater depth of explanation to the TAs' practices and future research should certainly include them as data sources.

6.2 FUTURE DIRECTIONS

There are two separate but related topics that should be pursued in follow-up studies: 1) continued research on the impact of training sessions on TAs' knowledge, and 2) improved design and delivery of the sessions themselves.

6.2.1 Research on TA knowledge for teaching

With the identification of some of the deficits in the TAs' knowledge, future studies can further investigate their nature and impact. Also researchers might not just look for additional deficits, but also identify strengths in the TAs' knowledge on which future training sessions can be built. A study that would both give legitimacy to teaching and connect teacher training with deeper content knowledge might consist of tracking the physics performance of TAs who have gone through training sessions through a series of tests. The control group would be TAs who have not gone through teacher training. Learning to teach better involves not only reflection on pedagogy but also reflection and reorganization of subject matter knowledge. The process of reflection and reorganization leads to deeper content knowledge. Such a study would turn around the truism that *one learns something by teaching it*. Instead, it would provide evidence that in order to teach something well, one must have true mastery of it. Mastery is a necessary (but not sufficient) condition to effective teaching. Other powerful ideas that may be used to design research and explain results include the following three subsections.

6.2.1.1 School science versus scientist's science

The preparation of graduate students for teaching and for doing research is very different. Research preparation follows an apprenticeship model, where incoming graduate students often start by doing low-level, even menial tasks. (My first research experience was to sweep the floor of the lab. About one minute into the sweeping my advisor stopped me to demonstrate how to sweep a floor properly. Other jobs included fetching dry ice or liquid nitrogen, moving lab equipment, and organizing storage units.) Teaching is a much more abrupt transition. Many factors work against the success of this transition, including the perception, often accurate, that school science is a compilation of known facts and algorithms that have to be memorized (Anderson, 2003). Investigating TAs' conceptions of school science and supporting views of school science more akin to their research would likely open the door to the possibility of more effective teaching strategies.

6.2.1.2 The label "expert"

This idea was first brought to my attention in conversations about the NSF GK-12 Program with Prof. Jennifer Cartier. Graduate student Fellows in the program discussed the impact of being called a scientist on their own attitudes towards science and their work. Many were both labeled and viewed as "experts" for the first time. In a parallel situation, TAs are considered experts by their students, whether or not the label is explicitly applied. This may have both positive and negative implications for the TAs' teaching. A positive result might be a heightened sense of responsibility which will motivate them to prepare and teach their recitations the very best they can. A possible negative consequence is explored in the next subsection.

6.2.1.3 Immediate expertise

Immediate expertise is a contradiction in terms since true expertise requires long time periods of intense effort. TAs, however, become experts by title and status immediately, with no or very little training. Their students expect them to know the answers to problems, be kind and understanding, and help them navigate the courses they are taking. Professors expect them to run recitations smoothly, grade fairly and accurately, and in some cases to be seen but not heard, meaning not to create negative feedback from the students. Finally, TAs expect themselves to rise to these challenges and beyond, since they have now made the transition to graduate study. In truth, the TAs' prevalent response to being experts is to use their status to control recitations in a way that minimizes their required effort and their possible exposure with regards to their as yet insecure knowledge of physics.

The Department and its professors do not help by viewing teaching recitation as a mechanical activity. TAs solve problems while saying very little by way of new information. Student questions interfere with the flow and could expose gaps in the TAs' knowledge, so all parties are agreed that lecturing is best. Many professors do not observe recitations or otherwise become involved unless a student voices a concern, concerns which TAs can easily alleviate with easy quizzes and helpful exam tips. Though recitations account for 25% of the students' in-class time, TAs typically control less than 10% of students' grades. They make up and grade quizzes. They grade homework, but typically do not select the problems that are assigned. And with the introduction of web-based homework packages even grading of homework is eliminated. *Expect little and minimize impact* seems to be the motto, one that accords with a label of expertise masking deficiencies in knowledge.

6.2.2 Design of future training sessions

Future training sessions need to increase both the subject matter knowledge and the pedagogical content knowledge of TAs. As this study has shown, providing strategies alone is not enough to impact what happens during recitation. Each future training session should be accompanied with another training session targeting the specialized knowledge required to fully implement the strategies and tools derived from previous research on best practices.

6.3 TA QUESTIONS DURING RECITATION

The analysis of the transcripts of the questions asked by TAs during recitation adds another source of information regarding their subject matter knowledge. Table 36 describes the three categories of questions that emerged from analyzing the transcripts. As described by Chin (2006), productive questions come in many types but a key distinction is between closed, recall type questions and open-ended questions. An additional category that I inserted consists of questions which appear to be open-ended, but actually serve more of a rhetorical than productive purpose. These I call Open-Short Answer.

Question Category	Definition	Explanation or Example
Recall - Short Answer	• Nature of question is lower order, closed with a predetermined short answer. • Student does not answer or student answer is short.	What other forces are there? *Gravity.*
Open - Short Answer	• Nature of question is higher order, engages students to participate, typically calls for longer one- or two-sentence answers. • Takes the form of an open question. • Student does not answer or student answer is short.	• Are there any other questions? *Yes, number 4.* • Is that clear? *Yes.* • What is the cause of the normal force? *Gravity?*
Open - Discussion	• Nature of question is higher order, engages students to participate, typically calls for longer one- or two-sentence answers. • Takes the form of an open question. • Student provides longer answer.	What is the cause of the normal force? *The block cannot go through the surface. The table pushes the block up.*

Table 36: Question types.

Not asking a question, asking a recall question, or asking a seemingly open but short answer question are together classified as "lecture style" interactions. Asking truly open-ended questions in order to generate discussion are classified as "discussion style" interactions. The aggregate data from the written measures given in Table 37 show the predominance of lecture style interactions.

Interaction Style	Percentage Totals				
	TA		Class		
	Pre	Post	Pre	Post	Expert
Lecture	100%	94%	92%	87%	44%
Discussion	0%	6%	8%	13%	56%

Table 37: Interaction styles from the analysis of written measures.

The analysis of recitation observations yielded similar results. Another way to understand the question types is to divide them into those that might be employed to solve problems versus teach problems, as shown in Table 38.

Used for solving problems	Used for teaching problems
Recall	Open ended discussion
Fill-in-the-blank	
Yes-no	
Think aloud protocol	

Table 38: Questions employed for different purposes.

Question types not only provide insight into the TAs' approach to teaching, but more importantly they also provide insight into TAs' knowledge about the subject they are teaching. Carlsen (1991) reported that teachers discouraged student questions on topics that they did not know a lot about. They controlled the discourse by limiting students' opportunities to speak.

According to the categories above, control came through a lecture style interaction and question types that might be used to solve problems. Open-ended discussions were avoided.

6.4 FINAL THOUGHTS

Graduate students are at the beginning of their professional careers. Their potential for societal impact throughout their careers is in many ways larger from their teaching than their research. Accordingly departments must allocate resources to train TAs and connect effective teaching to professional advancement in a meaningful way for faculty. Both of these steps face hurdles in large research universities where a greater emphasis on teaching is seen as taking time of graduate students and faculty away from their research programs.

Concretely, future training sessions in the Department need to focus on both proven tools and strategies, many of which have been documented in the PER literature, and the knowledge needed for the successful implementation of such tools and strategies. The latter training sessions align with current educational research in a variety of contexts as well as with the findings of my research. The effective use of representations, in particular, requires a special type of subject matter knowledge that cannot be assumed to be part of the knowledge base of successful graduate students in physics. The pivotal role this specialized content knowledge plays warrants its integration into the *Teaching of Physics* course.

In addition, studies on future training sessions need to further illuminate the correlation between specialized knowledge and the use of tools and strategies. The research on specialized knowledge is still exploring the connections between types of knowledge and teachers' practices across many domains. Preliminary findings indicate that pursuing the connections is a worthwhile and rich line of inquiry, though the recommendations that emerge are not prescriptive.

APPENDIX A

WRITTEN MEASURES AND TRAINING SESSION MATERIALS

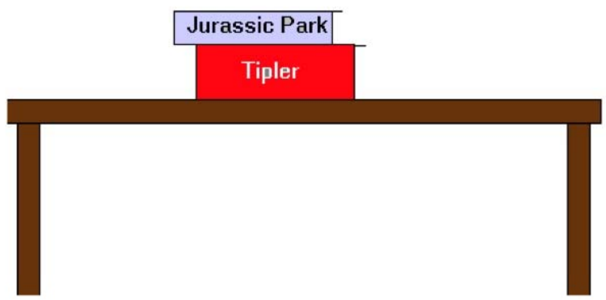
First TA Training Module Name_________________________
Sept. 14, 2007

Some students have emailed you about the question given below, asking that you go over it in recitation.

Two books are at rest on a table as shown in the figure. The top book (Jurassic Park) weighs 5N while the bottom book (Tipler) weighs 9N.

a) Draw a free body diagram showing all of the forces acting on the bottom book.

b) For each force in your diagram, list the object that causes the force.

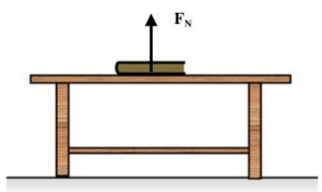


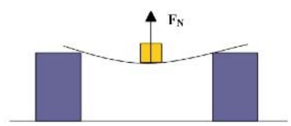
1) Describe the steps you would take in preparing to go over this problem in recitation.

2) Suppose that during the recitation a student asks: “I don’t understand where the normal force is coming from?” Write how you would respond to the student.

Second TA Training Module Name ______________________________
Friday, Sept. 28, 2007

A TA is preparing to teach a recitation explaining the normal force. He wants to use the example of a book at rest on a table, and has found three diagrams he might share with the class. You happen to meet the TA in the hallway, and he asks you for your advice: Which diagram should he use? Should he use one, two, or all three? What should he say about the diagram(s)?





Write below the advice that you give to the TA.

First TA Training Module
Sept. 14, 2007

Task 1

1. Discuss the following questions in your small groups. Write your answers on the white board. You may draw on what you wrote for question 3) on the Minstrell article.

   What might you do if you are struggling with a physics concept? (You might be studying for an exam, working on a homework set, or preparing a presentation.)

   a. What types of things or kinds of interactions help you?

   b. What types of things or kinds of interactions do not help you?

<u>Task 2</u>

Scenario: A TA stands at the front of the classroom next to a desk with her physics textbook on it, engaging her students in the following discussion.

TA: What keeps the book at rest on the table?
S1: Gravity pulling it downward.
(...Long awkward silence...)
TA: Okay, but the book is not falling down.
S2: That's right, because the table is in the way.
(...Another long awkward silence...)
TA: Let me rephrase. What are the forces acting on the book at rest on the table?
S3: Gravity.
(...Silence...)
TA: And...
S4: And the table pushing upward on it.
(Laughter from several members of the class.)
S2: The table cannot exert a force – like I said it is just in the way of the book falling down.
TA: Okay, let's do this. Please take out a sheet of paper and draw a diagram of the situation. Will S2 and S4 please share their diagrams.

Draw the pictorial or free body diagram that S2 drew on your white board labeling it *Student Alternate View*. Also draw S4's diagram labeling it *Target View*.

<u>S2 - Student Alternate View</u>	<u>S4 - Target View</u>

Discuss the following questions in your small groups, writing the answers to each pair of questions on a white board.

1. Elicit – tell me more!
   a. What comments by the TA elicit more information?
   b. What is the difference in the two diagrams?

2. Understand – do I really get what my students are thinking?
   a. What are the cues that the TA is understanding the students (both S2 and S4) real issues?
   b. How did S2 and S4 arrive at their different diagrams? (What line of reasoning did they use?)

3. Addressing – strategies for explaining.
   a. What scenario has the TA set up for addressing the students' views?
   b. How would you make the case to your students that S4's diagram is more powerful than S2's diagram? That is, how would you argue that the *target view* supports a wider range of explanations than the *alternate view*? (For example, you might give a different scenario that highlights a force exerted by a table.)

Task 4
A strategy for explaining...

Now we are going to work through a well-researched response to the S2's alternate view that tables cannot exert a (normal) force.

1. Write on the white board what you observe about following materials.

	Observations
Spring	
Foam	
Plastic	
Table	

2. Guided by your observations and the table below, how would you use these materials to design a recitation activity to aid S2 in moving towards the target view?

Common Student Preconceptions		Target Ideas
Incorrect	**Correct**	
An inanimate object like a table cannot exert a force	A spring can exert a force	An inanimate object can exert a force
An inanimate object like a table only blocks the movement of the book (but does not exert a force)	Springy objects compress according to the force or weight put on them	An inanimate object can exert a force
The table is not strained by the book	Springy objects compress according to the force or weight put on them	The table deflects (microscopically)

Plan for recitation (write on white board):

Second TA Training Module
Friday, Sept. 28, 2007

<u>Problem 9</u>

You are traveling in your 2000 kg car at 20 m/s up a hill with a 6.0° incline when you see a goose crossing the road 24 m in front of you. You know from previous experience that when you hit the brakes, a 16,000 N friction force opposes the car's motion. Will you hit the goose?

A. What type of a problem is this? That is, what principle can be used to solve this problem?

B. One of your students is struggling with this question. He thinks he has all of the individual components correct, but he is not sure how to set up the problem. How would you explain a strategy used to solve this problem to the student? Please be specific, using the set-up of the problem given above.

C. What representations of the problem (pictures, diagrams, charts, graphs) might you use to illustrate your explanation in B? Please explain the value of your representation in helping the student understand.

Third TA Training Module Name________________________________
October 19, 2007

<u>Problem 9</u>

You are traveling in your 2000 kg car at 20 m/s up a hill with a 6.0° incline when you see a goose crossing the road 24 m in front of you. You know from previous experience that when you hit the brakes, a 16,000 N friction force opposes the car's motion. Will you hit the goose?

A. Draw an energy bar chart (from the previous training) for this problem.

B. Is the frictional force represented as doing work in your bar chart?
   If so, why? (That is, how did you decide to include it as work?)
   If not, why? (That is, how did you decide not to include it as work?)

Second TA Training Module on Work-Energy
Friday, September 28, 2007

Group A

<u>Problem 1</u>

You're outside a spacecraft, pushing on a heavy box whose mass is m = 2000 kg. You exert a force F = 400 N while the box moves through a displacement d = 0.3 m. The box slows down but does not change direction due to the force. Initially the box had a speed of v = 0.7 m/s.

a) How much work do you do?

b) What is the final kinetic energy of the box?

c) What is the final speed of the box?

A student in your recitation asks you to explain Problem 1. Use the following interaction to guide your explanation to the student and the rest of the class. Explicitly indicate where the information from the interaction influences the solution you propose.

Divide your white board in half with a vertical line. On the left side write what you would write on the chalkboard. On the right side write out your accompanying explanations using the actual words you would say.

<u>TA/Student Interaction:</u>

TA: Are there any questions on the homework?
S: Yes, Problem 1.
TA: Any specific part of Problem 1?
S: I'm not sure.

Second TA Training Module on Work-Energy
Friday, September 28, 2007

Group B

Problem 1

You're outside a spacecraft, pushing on a heavy box whose mass is $m = 2000$ kg. You exert a force F = 400 N while the box moves through a displacement d = 0.3 m. The box slows down but does not change direction due to the force. Initially the box had a speed of v = 0.7 m/s.

a) How much work do you do?

b) What is the final kinetic energy of the box?

c) What is the final speed of the box?

A student in your recitation asks you to explain Problem 1. Use the following interaction to guide your explanation to the student and the rest of the class. Explicitly indicate where the information from the interaction influences the solution you propose.

Divide your white board in half with a vertical line. On the left side write what you would write on the chalkboard. On the right side write out your accompanying explanations using the actual words you would say.

TA/Student Interaction:

TA: Are there any questions on the homework?
S: Yes, Problem 1.
TA: Any specific part of Problem 1?
S: I'm not sure.
TA: Were you able to calculate the work done?
S: Yeah.
TA: What did you get?
S: 120 Joules.
TA: Okay, that seems correct. Let me take it from there.

Second TA Training Module on Work-Energy
Friday, September 28, 2007

Group C

Problem 1

You're outside a spacecraft, pushing on a heavy box whose mass is m = 2000 kg. You exert a force F = 400 N while the box moves through a displacement d = 0.3 m. The box slows down but does not change direction due to the force. Initially the box had a speed of v = 0.7 m/s.

a) How much work do you do?

b) What is the final kinetic energy of the box?

c) What is the final speed of the box?

A student in your recitation asks you to explain Problem 1. Use the following interaction to guide your explanation to the student and the rest of the class. Explicitly indicate where the information from the interaction influences the solution you propose.

Divide your white board in half with a vertical line. On the left side write what you would write on the chalkboard. On the right side write out your accompanying explanations using the actual words you would say.

TA/Student Interaction:

TA: Are there any questions on the homework?
S: Yes, Problem 1.
TA: Any specific part of Problem 1?
S: I'm not sure.
TA: Were you able to calculate the work done?
S: Yeah.
TA: What did you get?
S: 120 Joules.
TA: Okay, that seems correct. What about the velocity?
S: I got 0.78 m/s.
TA: That's where the problem is!

Second TA Training Module on Work-Energy
Friday, September 28, 2007

Group D

Problem 1

You're outside a spacecraft, pushing on a heavy box whose mass is $m = 2000$ kg. You exert a force F = 400 N while the box moves through a displacement d = 0.3 m. The box slows down but does not change direction due to the force. Initially the box had a speed of v = 0.7 m/s.

a) How much work do you do?

b) What is the final kinetic energy of the box?

c) What is the final speed of the box?

A student in your recitation asks you to explain Problem 1. Use the following interaction to guide your explanation to the student and the rest of the class. Explicitly indicate where the information from the interaction influences the solution you propose.

Divide your white board in half with a vertical line. On the left side write what you would write on the chalkboard. On the right side write out your accompanying explanations using the actual words you would say.

TA/Student Interaction:

TA: Are there any questions on the homework?
S: Yes, Problem 1.
TA: What type of a problem is this?
S: It is a work-energy problem.
TA: Okay, so what are the different contributions to the work or energy?
S: Well, there is work done by the person and there is kinetic energy.
TA: Good. And what do we know about the kinetic energy?
S: I'm not sure.
TA: Okay, well let's start there.

Task 3

Use the work-energy bar chart as a tool for explaining Problem 1 in your recitation. Assume that you know students had difficulty understanding the contribution due to work.

Again, divide your white board in half with a vertical line. On the left side write what you would write on the chalkboard. On the right side write out your accompanying explanations using the actual words you would say.

Problem 1

You're outside a spacecraft, pushing on a heavy box whose mass is $m = 2000$ kg. You exert a force F = 400 N while the box moves through a displacement d = 0.3 m. The box slows down but does not change direction due to the force. Initially the box had a speed of v = 0.7 m/s.

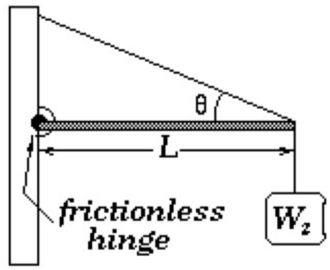
a) How much work do you do?

b) What is the final kinetic energy of the box?

c) What is the final speed of the box?

Third TA Training Module Name________________________________
October 19, 2007

Problem 1



A beam (L = 0.8 meters) with weight W_1 is attached to a wall by a hinge and a rope that extends from the opposite end of the beam to the wall. The rope makes a 25° angle with the beam. A block of weight W_2 hangs from the beam. If W_1 = 0.4 kg and W_2 = 2.1 kg, find the force exerted by the hinge.

C. What type of a problem is this? That is, what principle(s) can be used to solve this problem?

D. What parts of this problem might be difficult for students? Please be specific.

E. For each difficulty listed above, please give an example of what you would say or do to address the difficulty.

F. If you were to solve this problem, you would need to define an axis of rotation.
Briefly, what would you say to a student who chose the axis at:
The hinge?

The middle of the bar?

The end of the bar opposite the hinge where the two ropes are attached?

Third TA Training Module
October 19, 2007

Name________________________________

<u>Problem 1</u>

Your task is to design an artificial joint to replace arthritic elbow joints in patients. After healing, the patient should be able to hold at least a gallon of milk (3.76 liters) while the lower arm is horizontal. The bicep muscle is attached to the bone at a distance of 1/6 of the bone length from the elbow joint, and makes an angle of 80^{o} with the horizontal bone. For how strong of a force should you design the artificial joint? (The weight of the bone is negligible.)

Partially solve this problem as if you were preparing a detailed outline of the solution to hand out to your students. There is no need to find a numerical answer or to completely simplify all algebraic expressions.

Third TA Training Module on Equilibrium of a Rigid Body
Friday, October 19, 2007

Problem 1

Your task is to design an artificial joint to replace arthritic elbow joints in patients. After healing, the patient should be able to hold at least a gallon of milk (3.76 liters) while the lower arm is horizontal. The bicep muscle is attached to the bone at a distance of 1/6 of the bone length from the elbow joint, and makes an angle of 80º with the horizontal bone. For how strong of a force should you design the artificial joint? (The weight of the bone is negligible.)

Task 1

a. Partially solve Problem 1. You have already done this.

b. Next, in your groups write a detailed partial solution to Problem 1 that you would share with your students in recitation. Write down notes next to the solution about how you would share it in recitation. What is the learning focus for this problem that you will emphasize? What will you tell the students or what questions will you ask of them?

The notes are as important as the solution itself.

c. As a whole group, what similarities and differences do we see in the solutions? What do they emphasize? What do they assume about students' thinking?

Task 2

a. Review the five (5) partial student solutions to Problem 1.

b. Make a list of both the difficulties and strengths shown in the solutions. Look for both trends and differences across the solutions.

c. As a whole group, to what extent is there a match between the notes from the previous task and the difficulties/strengths found in the student solutions?

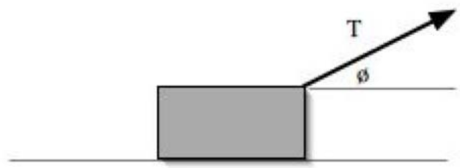
Task 3

a. Returning to the group solutions in Task 1, how would you revise them (if at all) after our discussion in Task 2? Make any changes either to the solution itself or to the notes about the solution that you feel would be helpful to your students.

b. As a whole group, what generalizations can we make about the changes made by the smaller groups?

Wrap-up

Problem 12.
If the block is sliding, is the frictional force equal to μmg (μ is the coefficient of friction)?



Recitation Scenario.

Student: Could you please do Problem #12?
TA: Any part of it in particular?
Student: Yeah, finding the normal force.
TA: What part about the normal force confused you?
Student: I thought the normal force equaled the weight of the block. I'm pretty sure I heard the professor say that in class today.
TA: *... see part (d) below...*

1. Please answer the following questions about the scenario.

(a) If the TA had turned to the board and solved the problem after the student's initial question, what would the TA have learned about the student's difficulty with this problem?

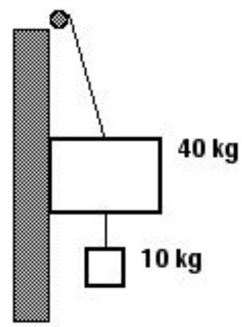
(b) Again, if the TA had stopped after the second statement by the student and solved for the normal force, what would the TA have learned about the student's difficulty with this problem?

(c) What student difficulty is expressed in the student's third statement?

(d) How would you respond to the student if you were the TA?

2. The following is a quiz in an introductory physics class. The quiz was given after a section on forces. In particular, the TA's intention was to test students' understanding of the normal force.

Quiz. Describe the forces on the 40 kg block, and explain why the block is not moving.



(a) What physics concepts and/or physics principles do students need to understand in order to answer this problem correctly?

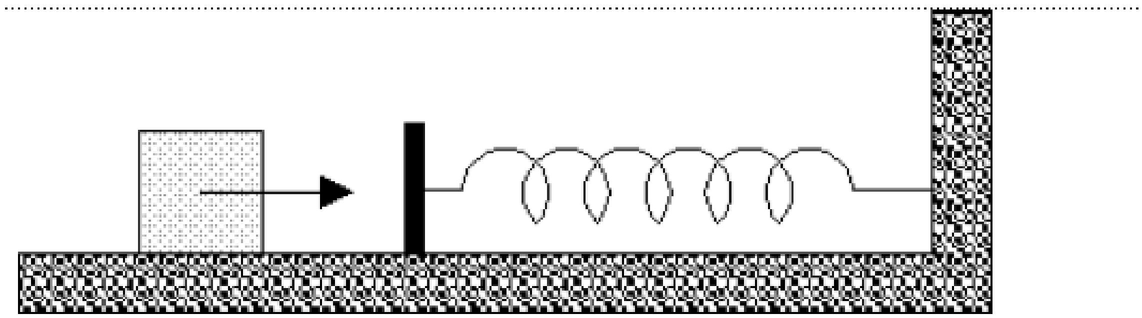
(b) What problems, if any, would you predict students would have with this question? What would cause them to struggle?

(c) What would you do to address the problems in (b)?

APPENDIX B

TRANSCRIPT OF ENERGY PROBLEM DURING RECITATION

A moving 3.40 kg block collides with a horizontal spring whose spring constant is 279 N/m.



The block compresses the spring a maximum distance of 14.00 cm from its rest position. The coefficient of kinetic friction between the block and the horizontal surface is 0.240. What is the work done by the spring in bringing the block to rest?

-2.73 J

Computer's answer now shown above. Tries 0/10

How much mechanical energy is being dissipated by the force of friction while the block is being brought to rest by the spring?

1.12 J

Computer's answer now shown above. Tries 0/10

What is the speed of the block when it hits the spring?

1.51 m/s

Computer's answer now shown above. Tries 0/10

Problem Statement From LON-CAPA

START

3:35 OK, so the first question was a spring and a block problem.
Y'all want to talk about this one?
Anyone else have trouble with this one?
Ss: Yeah.
You had trouble solving for what?
S: Number 1, part b. The first part was easy.
Part b. Remember, you have a block which is running into a spring.
Right?
And it's got some energy stored...
and it's released...it ejects the block.
Given the amount of work that the spring does on the block,
find out what distance the spring must have been compressed...
so that was the first part.
How was that?

S: The first part was easy.
So this is the common thing for these energy problems in the first [*homework*] set.
People seem to have trouble with ones
where they actually have to apply the conservation of energy,
whereas if you just asked how much work was done
by this one component of the system
then you could just sort of plug in a formula...
that was more straight-forward.
But the conservation of energy problems are
the least formula driven problems you've had yet.
They will require you to think of the physical intuition behind what's going on.
And there are lots of ways to think about them.
That why they're harder I think.
It is less straight-forward to make them a systematic formula-driven process.
There is another element to the physics that you have to learn,
beyond just extracting givens and plugging in equations.
So this is a good example of that.
Okay, so people seem to get the first part of this problem,
which was that you have some mass, some block,
sliding on a surface that does have friction,
so there is a kinetic coefficient of friction.

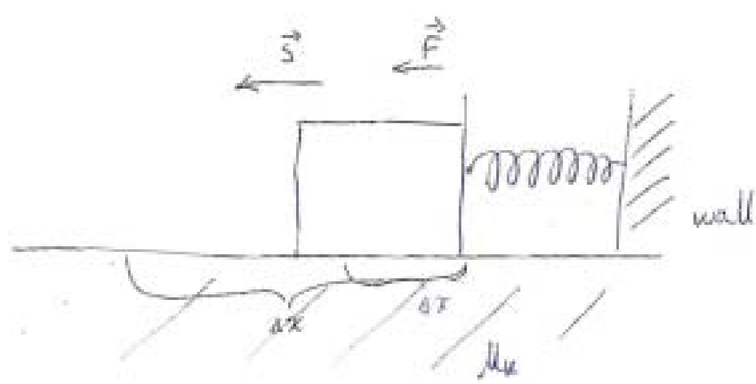
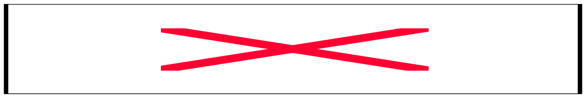


Diagram 1.
And you also know that it is in contact with the spring.
So you have some spring *...drawing on board...*
and it's attached to a wall.
The block is in contact with it.
For the first part you are told that the spring is initially compressed.
And you are given that it's compressed and released
so that the block goes sprinting away.
And you are told how much work the spring does on the block
during the expansion phase.
During the phase went the spring goes from being compressed to equilibrium.
So you're given the work.



Equation 1.

Okay, it's some number. For me it was 1.6 Joules.
6:45 And you have to find out how much the spring was compressed initially.
So how did you do it?
S: I just plugged into $1/2\ k\ x^2$
So you set it equal to $1/2\ k\ x^2$

$$\frac{1}{2} k x^2$$

Equation 2.

At this point everyone has covered
the formula $1/2\ k\ x^2$ for the work done by a spring.
So if you knew your formula,
you could plug and chug your way through this one.

APPENDIX C

STUDENT QUESTIONS DURING RECITATION

1. Questions about whether “k” is the spring constant or kinetic energy at the <u>end</u> of a 40-minute discussion:

Did anybody else have a question about this?
S: In the spring problem k was kinetic energy as well, right?
Sorry?
S: In the spring problem was k for kinetic energy as well?
Yeah.
Aaaa...
Ss: *...noise...*
No, k is the spring constant.
S: Okay, it was getting confusing.
No, there’s two k’s.
K is like this ubiquitous constant that is used in math.
That’s why sometimes I write it [*kinetic energy*] as a T to separate those two.
What I will try to do is a big K for kinetic energy
and a small k for the spring constant.
If you get confused, sorry, just shout out.
Okay, so are you all ready for a quiz?
THE END

2. Questions about defining an angle used in the problem at the end of a 40-minute discussion:

So any questions about this part?
S: At the beginning of the problem when you define the angle,
can you get to the angle from Fg,
I mean, going around in a circle rather than against the y-axis...unintelligible...x-axis...
37:29 So in cases where you're given...
I mean you are free to find the angle however you want.
It seems simplest to me to write beta in this way
so that we could see what Fg was going to be as quickly as possible.
As opposed to having to use the cosine of 2 hundred something degrees.
S: But it's the same value?
Yes, it's the same value.
It will give you the same result.
It is not going to be the same value,
because this theta is very small and this theta is very large.
But you get the same thing, provided you take into account your signs appropriately.
Okay, so again this was a long problem
but all we did was apply the exact same methods as all the force problems, right?
We wrote down F equals ma.
We figured out what the acceleration was.
We wrote down our free body diagram to figure out the sum of the forces.
We broke that down into components and solve F equals ma.
We have been doing this a lot, this is just a longer problem.
So don't be too intimidated by it's got a bunch of steps.
THE END

APPENDIX D

INTERVIEW WITH TA ABOUT DEFINING THE SYSTEM IN ENERGY PROBLEMS

1. Interviewer: Let me just start by asking you – you said you feel like you have more trouble with this material than the previous [kinematics] – let me just ask you what you mean by that.

2. TA: Well I think I feel more comfortable teaching material which can be easily systematized,
3. because if I just give a clear presentation of the system for solving problems,
4. the students will learn how to effectively solve the problems.
5. Whereas with energy problems
6. there is a lot more physical intuition that needs to be imparted on the students
7. than, for example, kinematics, and I think that's what I meant.

8. Interviewer: Okay.
9. Let's take that problem you started with today.
10. Can you just talk about that physical intuition versus systematic approach in that concrete example [block and spring problem] just to give some particulars
11. or if that wasn't a problem that highlighted what you were struggling with then maybe we could talk about another problem.

12. TA: No, that's the best example I have at hand for a problem that illustrates this difference.
13. Okay, with comparison to kinematics,
14. teaching that [kinematics] is more straight-forward to me because the goal from the extract-the-physics piece is find three givens.
15. Okay so that is a very clear thing.
16. So when you extract the three givens,
17. step two, find the equation which is missing the variable that you are not looking for.
18. Step three, solve for the variable of interest from the relevant equation.
19. That is solving problems of constant acceleration kinematics.

20. Interviewer: Yeah. There is a very clear...

21. TA: There is a very methodical way of doing it and it works every time.
22. If you do this, you will get the right answer.
23. It's good that something that clear cut happens early in the term because it builds confidence.

Interruption.

24. TA: So the other example in contrast with energy problems,
25. I can write down Work external + U initial + K initial = U final + K final
26. and then we could plug and chug our way through it,
27. but for one, they never seem to learn anything from that,
28. it doesn't seem to help them translate problem to problem,
29. and also there is a significant subtlety in what work external means,
30. because what you're considering external depends on what you've lumped into your potential energy.
31. You can consider gravity as an external working force if you don't consider mgh the potential.
32. Like let's say you have a spring which operates in the vertical direction.
33. Whatever you want to call your potential energy.
34. Maybe you want to call it both, maybe just one, and everything else has to be lumped into work.

35. Interviewer: What's the defining criterion which lumps things in or out, into work or not.

36. TA: I don't have one, because I don't think it matters.
37. I think there are plenty of problems where you can solve it in both ways.

APPENDIX E

QUESTIONNAIRE

Name______________________________ Date_________________

University of Pittsburgh
Department of Physics and Astronomy

Teaching Questionnaire

This year is the second year that Prof. Peter Koehler is teaching *Teaching Physics*. With the help of Prof. Chandralekha Singh and graduate student Stephen Pellathy, the course has undergone and continues to undergo major revisions. Your answers to this questionnaire will become part of the ongoing efforts to improve this course.

Answer all questions to the best of your knowledge. Do not skip any questions.

Avoid guessing. Your answers should honestly reflect your experiences and what you think.

Note that these questions are not multiple-choice. Some are open-ended, and others require you to rank your response on a scale between two end points.

Adapted from Nyquist, J.D. and Wulff, D.H., 1996. Working Effectively with Graduate Assistants, Sage Publications, Thousand Oaks, CA, p. 28-31. See http://www.ocean.washington.edu/people/faculty/mcmanus/taprep.html. Further additions based on questions from E. Etkina, Rutgers University.

Please answer these general questions.

1. How many years of physics have you studied:
   Before undergraduate = _____ years
   Undergraduate = _____ years
   Graduate = _____ years

2. How would you rate your content knowledge of introductory physics on a scale?
   (Circle an "X".)
   Expert Proficient Beginner
   X--------X--------X--------X--------X--------X--------X--------X--------X--------X

3. How would you rate your knowledge of physics teaching (skills, methods, strategies) on a scale?
   (Circle an "X".)
   Expert Proficient Beginner
   X--------X--------X--------X--------X--------X--------X--------X--------X--------X

4. Detail your teaching experience, if any:
   List courses you have taught, including level, title of course, teaching role, and institution or organization.
   (Teaching roles = sole instructor, team teacher, TA with own section, demonstrator, grader or tutor, other experience.)

5. Please briefly describe any training programs, short courses, or workshops on teaching methods or teaching effectiveness in which you have participated:

6. Which of the above experiences (courses you have taken, your teaching experience, or training programs) influenced your teaching style?

7. What do you think a person needs to know to be a good physics TA? Please put your answer in order, starting with the most important thing first.

8. What do you think a person needs to able to do to be a good physics TA? Again, please put your answer in order, starting with the most important thing first.

9. Describe what you think being a good TA is about; that is, what does it mean to TA physics well?

10. Make a list of things you think you need to learn to be a better physics TA.

Please take a few moments to identify your level of **experience** and **interest** in each of the following aspects of teaching by circling the appropriate numbers:

11. Holding office hours for students
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

12. Assisting in large enrollment classes
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

13. Working with students of diverse backgrounds
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

14. Teaching labs
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

15. Teaching recitations
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

16. Developing demonstrations for labs, recitations, or classes
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

17. Teaching (independently) large classes
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

18. Teaching (independently) small classes
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

19. Leading class discussions
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

20. Using active learning methods (in which students are actively engaged in learning)
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

21. Organizing and managing small groups of students
    Little experience 1 2 3 4 5 Extensive experience
    Little interest 1 2 3 4 5 Extensive interest

22. Using technology in teaching (computing, multimedia, Web-based, etc.)
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

23. Developing multiple choice tests
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

24. Developing essay tests
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

25. Developing problem-solving tests
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

26. Assigning grades
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

27. Designing courses and constructing syllabi
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

28. Responding to challenging classroom-management situations
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

29. Learning how to know your students better (their knowledge, skills, misconceptions)
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

30. Learning teaching strategies for introductory physics
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

31. Improving your teaching
Little experience 1 2 3 4 5 Extensive experience
Little interest 1 2 3 4 5 Extensive interest

32. Teaching as a part of your **future** professional duties
~~Little experience 1 2 3 4 5 Extensive experience~~
Little interest 1 2 3 4 5 Extensive interest

Please answer these questions about your teaching strengths and concerns.

33. What do you think are your teaching strengths?

34. What are your major concerns about teaching?

35. As you anticipate your appointment as a TA, lab instructor, or grader, what do you feel you most need during our course *Teaching Physics*?

36. If you are considering a possible career track in academia as a faculty member, what do you feel you most need to prepare you to be a future faculty member?

37. What do you think an assessment of your TA or lab instructor performance should include that would be particularly beneficial to you in your professional development as a teacher?

APPENDIX F

INTERNAL REVIEW BOARD APPROVAL

University of Pittsburgh
Institutional Review Board

3500 Fifth Avenue
Ground Level
Pittsburgh, PA 15213
(412) 383-1480
(412) 383-1508 (fax)
http://www.irb.pitt.edu

Memorandum

To:	STEPHEN PELLATHY
From:	SUE BEERS PHD, Vice Chair
Date:	8/21/2007
IRB#:	PRO07070093
Subject:	Training physics graduate teaching assistants

Your research study has received expedited review and approval from the Institutional Review Board under 45 CFR 110.(7).

Please note the following information:

Approval Date:	8/21/2007
Expiration Date:	8/20/2008

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. The IRB Reference Manual (Chapter 3, Section 3.3) describes the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

The protocol and consent forms, along with a brief progress report must be resubmitted at least **one month** prior to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

Please be advised that your research study may be audited periodically by the University of Pittsburgh Research Conduct and Compliance Office.

University of Pittsburgh
Institutional Review Board

3500 Fifth Avenue
Ground Level
Pittsburgh, PA 15213
(412) 383-1480
(412) 383-1508 (fax)
http://www.irb.pitt.edu

Memorandum

To:	STEPHEN PELLATHY
From:	CHRISTOPHER RYAN, Vice Chair
Date:	8/31/2007
IRB#:	PRO07070093/MOD07070093-01
Subject:	Training physics graduate teaching assistants

The modifications requested for the above referenced research study has received expedited review and approval from the Institutional Review Board.

Please note the following information:

Approval Date:	8/31/2007
Expiration Date:	8/20/2008

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. The IRB Reference Manual (Chapter 3, Section 3.3) describes the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

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Please be advised that your research study may be audited periodically by the University of Pittsburgh Research Conduct and Compliance Office.

University of Pittsburgh
Institutional Review Board

3500 Fifth Avenue
Pittsburgh, PA 15213
(412) 383-1480
(412) 383-1508 (fax)
http://www.irb.pitt.edu

Memorandum

To: Stephen Pellathy

From: Sue Beers , Vice Chair

Date: 1/21/2009

IRB#: REN08120046 / PRO07070093

Subject: Training physics graduate teaching assistants

Your renewal for the above referenced research study has received expedited review and approval from the Institutional Review Board under:
45 CFR 46.110.(7) characteristics/behaviors

Please note the following information:

Approval Date: 1/20/2009
Expiration Date: 1/19/2010

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. The IRB Reference Manual (Chapter 3, Section 3.3) describes the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Events Coordinator at 412-383-1480.

The protocol and consent forms, along with a brief progress report must be resubmitted at least **one month** prior to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

Please be advised that your research study may be audited periodically by the University of Pittsburgh Research Conduct and Compliance Office.

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